NASA Glenn Safety Manual

CHAPTER 7 - PROCESS SYSTEMS AND STRUCTURAL SAFETY

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7.1 SCOPE

This Chapter presents general safe practices relating to all pressure vessels and pressurized systems. Specific safety considerations are included for pressure systems at the Glenn Research Center. This chapter contains sections devoted to a particular commodity, such as cryogenics, pressurized gases, steam, cooling water, compressed air, and such. Each section addresses recertification requirements and design, testing, and safety considerations.

7.2 APPLICABILITY

The provisions of this chapter are applicable to GRC employees and to all other agencies, organizations, and contractor personnel, who design, construct, inspect, operate, maintain, repair, or manage pressure vessels, pressure systems, and load bearing structures within the confines of the Glenn Research Center at Cleveland and Plum Brook Station.

7.3 AUTHORITY

The authority for the process systems and structural safety plan comes from NPR 8710.5A, “NASA Safety Policy for Pressure Vessels & Pressurized Systems”; NPR 1700.6A, “Guide for Inservice Inspection of Ground-Based Pressure Vessels and Systems”; and STD 8719.7, “Facilities System Safety Guidebook”.

7.4 RESPONSIBILITIES

General responsibilities of individuals, managers, and organizations regarding safety of Process Systems and Structures are specified in Chapter 1A of the Glenn Safety Manual. Functional responsibilities of organizations tasked with specifying, reviewing, and implementing safety requirements applicable to pressure vessels, pressurized systems, and load bearing structures are as follows:

7.4.1 Process Systems Safety Committee

The primary responsibility of the Process Systems Safety Committee is to ensure that the central process systems are designed and operated safely. Included as part of the responsibilities of the Process Systems Safety Committee is the responsibility to oversee application of NPR 1700.6A, Guide for Inservice Inspection of Ground-Based Pressure Vessels and Systems" to Glenn Research Center pressure vessels and systems.

7.4.2 Glenn Safety Office

The Glenn Safety Office (GSO) is responsible for maintaining the Glenn Safety Manual (GSM). The GSO ensures that all drafts and updates of new material are properly reviewed and edited prior to publication. The GSO has the authority to terminate any operation of questionable safety until an appropriate review and determination can be made. Exercise of this authority requires immediate notification to the Area Safety Committee chair and the Recertification Manager.

7.4.3 Quality Management Office

It shall be the responsibility of the Quality Management Office to periodically monitor, assess, and audit GRC implementation of the quality requirements specified in the welding codes and associated GRC welding documents.

It shall be the responsibility of the Engineering and Technical Services Directorate to ensure that all pressure vessels, pressurized systems, and load bearing structures designed or specified by the Directorate, are done in accordance with the applicable codes. The responsibilities shall include specifying appropriate welding procedures, inspections, evaluations, and tests.

The Directorate is responsible for implementation and management of the GRC Recertification Program. It shall be the responsibility of the Recertification Program Manager to implement NPR 1700.6A, "Guide for Inservice Inspection of Ground-Based Pressure Vessels and Systems" at the Glenn Research Center and Plum Brook Station.

7.4.4 Facilities Engineering Division

It shall be the responsibility of the Facilities Engineering Division (FED) to provide engineering, operations, maintenance, and protective services that are customer focused in support of the mission of GRC. Typical systems under FED responsibility include the Central Air Systems (combustion air and altitude exhaust), institutional systems (steam, domestic and chilled water, low pressure natural gas, and carbon dioxide), high-pressure gas and cryogenic systems, mobile equipment (tube trailers, cryogenic dewars, and fuel trailers), and cooling tower water systems.

It shall be the responsibility of the FED to ensure all construction contractors performs design activities in accordance with NFGS-150500 (Basic Mechanical Materials and Methods). All welding shall be performed in accordance with the ASME Boiler and Pressure Vessel Code, AWS D1 Structural Code, and ANSI B31 Piping Code. Welding procedure specifications shall be qualified in accordance with ASME Boiler and Pressure Vessel Code Section IX. The quality and inspection of the welds shall be in accordance with the applicable code and shall be specified on the appropriate documentation.

7.4.5 Test Installations Division

The Test Installations Division shall ensure that requests for fabrication, installation, and repair of pressurized systems, vessels, and structures are completed in accordance with specific welding codes and qualified welding procedure specifications.

7.5 CODES AND STANDARDS

The following codes and standards relate to the safe design, construction, operation, maintenance and repair of pressure vessels, pressurized systems, and load bearing structures. These codes and standards establish minimum safety requirements. Pressure vessels, pressurized systems, and load bearing structures at the Glenn Research Center shall meet or exceed these requirements.

7.5.1 Pressure Vessel Codes

The ASME Boiler & Pressure Vessel Code, Section I applies to boilers; Section VIII applies to pressure vessels.

7.5.2 Piping Codes

The ASME B31 codes apply to piping (e.g. ASME B31.1, Power Piping; ASME B31.3, Process Piping; ANSI B31.5, Refrigeration Piping).

7.5.3 Structural Codes

The AWS D1 codes apply to welded load bearing structures (e.g. AWS D1.1, Standard for Steel Structural Code Welding; AWS D1.2/D1.2M, Structural Welding Code - Aluminum).

7.6 GRC DOCUMENTS ADDRESSING PROCESS SYSTEM/WELDING REQUIREMENTS

7.6.1 GRC Welding Quality Assurance Program Manual

NOTE: The GRC Welding Quality Assurance Program Manual (WQAPM) GRC-M0520.001 (Revision B, January 17, 2003), has been revised and is now available on-line. To access the on-line WQAPM from the Glenn ISO Homepage: pick BMS Library; thereafter pick Center Manuals, followed by picking Welding Quality Assurance Program Manuals.

The GRC Welding Quality Assurance Program (WQAP) Manual outlines weld joint design and inspection requirements and associated documentation requirements for new design pressure vessels, pressure systems, load bearing structures, welding performed within test cells or an area of research setup, or welding performed on flight hardware. All code welds made by GRC personnel shall be documented using a Welding Request Form.

Contractors shall document code welds in accordance with the requirements of the applicable welding code. All code welds shall be welded by certified welders using an approved Welding Procedure Specification (WPS). Welders shall be certified in accordance with Section IX of the ASME Code, AWS D1 Codes, or MIL-STD-1595, as applicable.

7.6.2 GRC Recertification Program Welding Manual

The GRC Recertification Program Manual identifies the documentation and procedural requirements for performing code welding on existing pressure vessels, pressure systems, and load bearing structures, or welding performed external to test cells or an area of research setup. The GRC Recertification Program Manual documents how GRC is implementing NPR1700.6A (Guide for Inservice Inspection of Ground-Based Pressure Vessels and Systems). Specific WPS's already approved for use on the Recertification Program are identified.

7.6.3 GRC Recertification Program Handbook

The GRC Recertification Program Handbook identifies how GRC is implementing the requirements of NPR 8710.5A, NASA Safety Policy for Pressure Vessels and Pressurized Systems; and NPR 1700.6A, Guide for Inservice Inspection of Ground-Based Pressure Vessels and Systems. No welding requirements are specified.

7.6.4 GRC Requirements and Criteria Manual for the Central Process Systems at GRC.

The Requirements and Criteria (R&C) Manual provides and documents the data and information necessary in the design, engineering, operations, and maintenance of the Central Process Systems at GRC. The Central Process Systems include:

a. All combustion air systems
b. The altitude exhaust system
c. The atmospheric exhaust fan system
d. The 125 psig service air system
e. The cooling tower water systems
f. The Carrier refrigeration chilled water system.

The R&C Manual identifies the specific welding codes followed in the design of existing Central Process Systems. The R&C Manual specifies welding codes that are detailed in the WQAP manual.

7.6.5 GRC-P7010.002, Configuration Control of Facilities

GRC-P7010.002 establishes a configuration management system for certain Glenn process systems. It specifies that a Process System Change Request (NASA C-29) must be completed and approved before a change is implemented to any of the specified process systems.

7.6.6 GRC Safety Manual, Chapter 7, Paragraph 7.20, Pressure System Testing Policy

Paragraph 7.20 of this Chapter defines testing requirements for existing and new ground-based pressure vessels and piping systems.

7.7 WELDED LOAD BEARING STRUCTURES

7.7.1 Design and Materials Requirements for Load Bearing Structures

Load bearing structures shall be designed to meet or exceed one of the following as applicable: AWS D1.1, Standard for Steel - Structural Code; AWS D1.2/D1.2M, Structural Welding Code - Aluminum). See the GRC WQAP Manual or the Recertification Program Welding Manual, as appropriate, for more information. (See 7.6.1 for WQAPM on-line access instructions)

7.7.2 Quality Assurance Requirements for Load Bearing Structures

<u>Qualification of weld process:</u> All welding, including repair, done under AWS Code must be performed using an approved Welding Procedure Specification (WPS), which details the weld parameters and joining configuration for the welder. See the Weld Quality Assurance Program (GRC WQAP) Manual or the Recertification Program Welding Manual, as appropriate, for more information. (See 7.6.1 for WQAPM on-line access instructions)

<u>Welder certification</u>: All welding under AWS Code must be performed using certified welders. See the GRC WQAP Manual or the Recertification Program Welding Manual, as appropriate, for more information. (See 7.6.1 for WQAPM on-line access instructions)

<u>Weld Inspection Requirements</u>: Visual inspection of materials and documentation shall be performed as necessary by a Certified Weld Inspector (CWI) prior to assembly, during assembly, during welding, and after welding to ensure proper workmanship. All required NDT shall be performed by inspectors certified to SNT-TC-1A. See the GRC WQAP Manual or the Recertification Program Welding Manual, as appropriate, for more information. The Welding Request Form (C-3054) is used to document the completion of all in-house welding including repair by NASA employees and their support service contractors.

7.8 PRESSURE VESSELS

7.8.1 Design Requirements for Pressure Vessels

For ensuring the structural integrity of PV/S and to minimize associated mishap potential, all pressure vessels, pressurized components, and pressurized systems are to be designed, fabricated, installed, operated, periodically inspected, maintained, repaired, and certified/recertified in accordance with applicable codes, standards, guides, and Federal and State regulations by the certifying authority having jurisdiction or qualified and accepted in accordance with program requirements.

<u>Stationary pressure vessels:</u> Stationary pressure vessels that (1) have a maximum allowable working pressure (MAWP) greater than 15 psig, with no limitation on size, or (2) have an inner diameter, width, height, or cross section diagonal exceeding 6 inches, or (3) are potentially lethal shall be designed in accordance with the rules of the "ASME Boiler and Pressure Vessel Code," Section VIII, Division I, "Pressure Vessels," or Division II, "Alternative Rules."

<u>Portable or mobile vessels:</u> Portable or mobile vessels used to transport pressurized or hazardous commodities shall be designed, maintained, and operated in accordance with 49 CFR (DOT regulations). Vessels designed and fabricated according to these regulations should not be specified for permanent installation in pressurized systems.

<u>Low-pressure tanks:</u> Stationary low-pressure tanks with MAWP between 0 and 15 psig that have a safety or environmental impact shall be designed in accordance with American Petroleum Institute (API) Standard 620, "Design and Construction of Large, Welded, Low-Pressure Storage Tanks"; API Standard 650, "Welded Steel Tanks for Oil Storage"; or an approved equivalent standard as determined by the Process System Safety Committee.

<u>Flammable and combustible liquid storage tanks and vessels:</u> Flammable and Combustible liquid storage tanks and pressure vessels shall be designed, fabricated, operated, and located in accordance with NFPA 30, "Flammable and Combustible Liquids Code."

<u>Service life of pressure vessels:</u> Service life, determined by acceptable analysis or empirical data, shall be based on testing and analysis of fatigue, corrosion, creep, other failure mechanisms, or a combination of mechanisms. Glenn pressure vessels shall have a minimum design service life of 10 years.

<u>Maintainability:</u> The designer shall provide for the following inspection and maintenance requirements:

a. Access for inspection, and adequate work space and work clearance
b. Interchangeability of like components, materials, and parts associated with the vessel

c. Use of manufacturers' standard components and parts, and use of items within Glenn supply inventories wherever practicable

Relief protection: All pressure vessels shall be provided with relief protection devices in accordance with the applicable division of Section VIII of the ASME Code.

a. The relieving capacity of such devices shall be established in accordance with the applicable division of Section VIII of the ASME Code.
b. Certification of flow capacity and marking of relief protection devices shall be in accordance with the applicable division of Section VIII of the ASME Code.

Corrosion allowance: For all stationary vessels, corrosion allowance shall be evaluated in accordance with ASME Code, Section VIII, Divisions I and II.

Vessel attachments: Design of and subsequent field alterations and changes to vessels shall minimize welding of attachments such as ladders, platforms, and pipe supports to the pressure boundary of the vessel.

7.8.2 Materials Requirements for Pressure Vessels

General requirements: Materials used in the construction of pressure parts of pressure vessels shall conform to a specification in the "ASME Boiler and Pressure Vessel Code," Section II. Allowable stress values are given in Section VIII, Division I or II. Materials used for non-pressure parts, and attached to the vessel, shall conform to the requirements of Section VIII.

Tanks: Materials for low-pressure tanks shall conform to American Society for Testing and Materials (ASTM) specifications.

Compatibility: To prevent chemical reactions (including corrosion) between the contained commodity and contacted materials, all materials for use in pressure vessels shall be selected on the basis of proven compatibility. Guidance on material selection for compatibility may be found in MIL-HDBK-5, ASME Section II, and MSFC-HDBK-527. Manufacturers' data can also provide guidance on material selection. Note the following restrictions:

a. When austenitic stainless steels are used, the welding process shall be qualified to ASTM-A262 or equivalent for the intended service, because these steels (300 series), when welded, are susceptible to intergranular corrosion due to carbide precipitation or sensitization. Guidance on corrosion protection may be found in the ASM "Metals Handbook of Corrosion: Vol13”.
b. Copper or copper-bearing materials shall not be used in ammonia service.
c. Aluminum storage vessels shall not be used in liquid oxygen service.

7.8.3 Quality Assurance Requirements for Pressure Vessels

Manufacturer: The pressure vessel manufacturer is required to maintain a quality control program in accordance with ASME Section VIII, Division I, Appendix 10, or Division II, Appendix 18. Documentation supplied by the manufacturer shall be adequate to verify design, material control, examinations and inspections, and welding. In particular, all welding personnel, procedures, and equipment shall be qualified in accordance with ASME Section IX.

Pressure testing: Pressure vessels shall be pressure tested in accordance with the "Glenn Pressure System Testing Policy” (Section 7.20).

Stamping: All newly fabricated vessels shall have a nameplate affixed, or be stamped, in accordance with the requirements in appropriate national consensus codes. All other vessels shall be identified as to maximum allowable working pressure (MAWP), test pressure, operating cycle, and temperature limits. In addition, the MAWP and system commodity name shall be painted in a conspicuous location on each stationary pressure vessel.

Records: A documentation file shall be provided for each vessel and tank. The documentation requirements are defined in the "Glenn Pressure Vessel/System Recertification Handbook."

Cleanliness: Contamination control requirements shall be established commensurate with actual needs and the nature of the system and commodity. Cleanliness requirements for oxygen service are described in Chapter 5 of this Manual.

7.8.4 Recertification Requirements for Pressure Vessels

All pressure vessels shall be certified in accordance ASME Code requirements. All pressure vessels shall be included in a comprehensive recertification program, in accordance with the "Glenn Pressure Vessel/System Recertification Handbook." Alterations or repairs to pressure vessels must be reviewed for compliance with applicable codes and standards and must be documented. Relief devices that protect pressure vessels from overpressure conditions are to be inspected and tested at intervals specified in the “Glenn Pressure Vessel/System Recertification Handbook”. A comprehensive nondestructive examination to recertify the vessel shall be performed at intervals not exceeding 20 years. (This recertification will help ensure continued safe operation of the vessel.)

7.9 PRESSURIZED SYSTEMS

7.9.1 General Requirements for Pressurized Systems

The design, material selection, fabrication, inspection, testing, and safeguarding of pressure systems can vary greatly in the effort to meet safety, functional, and cost objectives. This section sets forth minimum requirements for safe design of pressure systems.

7.9.2 Design Requirements for Pressurized Systems

Pressure systems and components shall be designed so that failure does not occur within expected design conditions. Piping systems shall be designed to meet or exceed one of the following, as applicable: ASME B31.1 "Power Piping" or B31.3 "Process Piping." Particular system hazards and functional requirements warrant specific design, quality of material, inspections, and tests. Therefore, competent engineering judgment in the design of all pressure systems is required.

<u>System analysis requirements</u>: Load, service life, and hazards must be considered when a system is being designed.

<u>Load</u>: All loads (direct and combined) on the system and its components shall be considered, including dynamic and static loads, thermally induced loads, external loads, and test loads. Codes establish specific load case combinations that must be compared with allowables. Minimum design shall be based on the worst case of expected load combinations. Loading frequency shall be used to evaluate safe life of the system on the basis of fatigue.

<u>Service life:</u> The service life shall be determined for system piping and components. Service life, determined by acceptable analysis or empirical data, shall be based on testing and analysis of fatigue, corrosion, creep, other failure mechanism, or a combination of mechanisms. Glenn systems shall have a minimum design service life of 10 years.

<u>Hazards</u>: In the selection of system configuration, materials, inspection, and test requirements, consideration should be given to potential system failures. Failure modes and effects analyses and other mitigation methods should be employed to ensure the general safety of personnel and the protection of equipment.

<u>Maintainability:</u> Pressurized system design shall emphasize the need for access, inspection, service, replacement, repair, and refurbishment.

<u>Mobile systems</u>: Mobile systems used to transport pressurized or hazardous commodities shall be designed, maintained, and operated in accordance with 49 CFR (DOT regulations).

Hazardous storage or waste systems: Hazardous storage or waste systems shall be designed, operated, and maintained in accordance with 40 CFR, Parts 260 to 265, "Protection of Environment."

Flammable and combustible liquid storage systems: Flammable and combustible liquid storage systems shall be designed, fabricated, located, and operated in accordance with NFPA 30, "Flammable and Combustible Liquids Code."

Relief protection: All pressure systems shall be provided with relief protection devices in accordance with the applicable fabrication and design codes. In addition, the following must be observed:

a. The relieving capacity of such devices shall be established in accordance with the applicable fabrication and design codes.
b. Certification of flow capacity and marking of relief protection devices shall be in accordance with the applicable fabrication and design codes.

Corrosion allowance: Corrosion allowance for all pressure systems shall be evaluated in accordance with the applicable design codes.

Supports and attachments: Design of and subsequent field alterations or changes to pressure systems shall minimize welding of attachments such as ladders, platforms, and pipe supports to the pressure boundary of the system.

7.9.3 Materials Requirements for Pressurized Systems

General requirements: Materials used in the construction of pressure system parts shall conform to one of the specifications listed in ASME B31.1 or B31.3.

Compatibility: All materials for use in pressurized systems shall be selected on the basis of proven compatibility. This will prevent chemical reaction between a reactive commodity and the contacted materials. Guidance on selecting materials for compatibility may be found in MIL-HDBK-5, AFML-TR-68-115, and MSFC-HDBK-527. When the system must accommodate corrosive conditions, the design must incorporate a corrosion allowance based on the design service life.

7.9.4 Fabrication, Installation, and Repair of Pressurized Systems

Fabrication, installation, and repair, including welding procedures and welder qualifications, shall be in accordance with ASME B31.1 or B31.3, or the National Board Inspection Code, as applicable. Potential detrimental effects, such as: intergranular corrosion, embrittlement, plastic deformation and excessive deflection, shall be evaluated and avoided.

7.9.5 Quality Assurance Requirements for Pressurized Systems

Pressure testing: Pressure testing shall be performed in accordance with the "Glenn Pressure System Testing Policy” (Section 7.20).

Relief protection: All portions of the pressure system that can be over pressurized by single component failure or any combination of valve sequencing or other possible events shall be provided with relief protection devices in accordance with ASME B31.3, Section 322.6.

7.9.6 Stamping (Labeling)

Pressure systems shall be marked and labeled in accordance with standard Federal and Glenn requirements.

7.9.7 Records

A documentation file shall be provided for each pressure system. The documentation requirements are defined in the "Glenn Pressure Vessel/System Recertification Handbook."

7.9.8 Cleanliness

Contamination control requirements shall be established commensurate with actual needs and the nature of the system and commodity. Cleanliness requirements for oxygen service are described in Chapter 5 of this Manual.

7.9.9 Recertification Requirement for Pressurized Systems

Prior to assembly, all new components in a pressurized system shall be certified in accordance with national consensus codes. All pressurized systems shall be included in a comprehensive recertification program. Alterations or repairs to pressure systems must be reviewed for compliance with applicable codes and standards and must be documented. Pressure vessels relief devices and components in pressurized systems at GRC are required to be inspected/recertified at regularly scheduled intervals. The required intervals are specified in "Inspecting and Recertification (I&R) Tables" contained in the GRC Recertification Handbook. Inspection frequencies are at 1, 2, or 5-year intervals depending on pipe diameter, pressure, volume, and fluid commodity. Comprehensive recertification of pressurized systems (including nondestructive examination) is required at 5, 10, or 20-year intervals depending on pipe diameter, pressure, volume, and fluid commodity. These inspection and recertification requirements will help ensure continued safe operation of the pressurized systems.

7.10 CRYOGENIC SYSTEMS

7.10.1 Description

This section discusses stationary cryogenic systems. Mobile cryogenic systems are addressed in Section 7.13 (Mobile Equipment) of this chapter. The Compressed Gas Association (CGA) defines cryogenic fluids as those with a normal boiling point lower than -238° F but other authorities set higher boiling points as the criteria (See Section 7.13.2, Definitions). At Glenn, cryogenic systems are used to store and distribute such cryogenic liquids as the following:

Approximate Normal boiling point			
Fluid	F°	R°	K°
Krypton	-243.13	216.54	120.29
Oxygen	-297.34	162.32	90.18
Argon	-302.57	157.10	87.28
Nitrogen	-320.45	139.22	77.35
Neon	-410.91	48.76	27.09
Hydrogen	-423.19	36.48	20.27
Helium	-452.07	7.60	4.22

A typical cryogenic system consists of a pressure vessel (called a dewar"), pressure-relief devices, control valves, and distribution piping. The dewar is a double-walled pressure vessel with the system fluid contained in the inner vessel. The space between the vessels is filled with a powdered insulation (or is super insulated) and is held at a vacuum with a vacuum pump, thereby providing an insulation barrier for the fluid in the dewar. A control system and pressure building coil allow the dewar to maintain an internal pressure. Cryogenic systems generally operate at pressures below 100 psig. Piping for cryogenic fluid distribution is either vacuum jacketed or rigid foam insulated to reduce boil off losses.

7.10.2 Requirements for Cryogenic Vessels and Systems

In addition to conforming to the general requirements for pressure system safety, cryogenic vessels and systems must adhere to specific and unique requirements.

<u>Cryogenic vessels:</u> Requirements for cryogenic vessels are as follows:

<u>Design</u>: Cryogenic vessels shall be designed in accordance with the ASME Code, Section VIII. When considering loadings, particular attention shall be given to the stresses from thermal contraction and expansion of the inner shell and support members. The outer shell of a multi-shell cryogenic vessel shall be designed for at least 15-psig external pressure.

Materials: Metals selected for use at cryogenic temperatures shall have no ductile-to-brittle transition. Many austenitic stainless steels (300 series), aluminum alloys, and nickel alloys exhibit this behavior. Guidance on material selection for compatibility with liquid oxygen, liquid hydrogen, and liquid fluorine may be found in AFSC DH-1-6.

Relief device: The inner vessel of a multi-shell cryogenic vessel shall have relief devices designed and maintained in accordance with Section VIII of the ASME Code. The outer vessel shall have relief protection to allow for a leak or failure of the inner shell.

Cryogenic systems requirements: Requirements for cryogenic systems vary, depending on the cryogen.

Inert cryogens: Materials used in cryogenic service shall be of proven compatibility and of sufficient ductility at design temperature to preclude brittle failure. System configuration, line sizes, and insulation shall be designed to prevent excessive thermal stress, geysering, and water hammer effects. Over-pressurization protection must be provided in system sections that can be isolated. Components shall be rated and designed to operate at cryogenic temperature or installed at a sufficient standoff distance to operate at rated temperatures. Relief valves shall be mounted vertically and with sufficient standoff distance to prevent the valve from icing or failing to operate. Relief valves shall relieve into a vent system or into an area where no harm will come to personnel or equipment. Manual valves shall have extended stems, with the stems oriented vertically to prevent exposure of the valve packing material to cryogenic temperatures. Vacuum insulation spaces shall be provided with over-pressurization protection in case of a leak in the pressure boundary of the inner transfer line.

Oxygen: Design and operation of systems for liquid oxygen storage shall conform to requirements contained in NFPA 50, "Standard for Bulk Oxygen Systems at Consumer Sites." Oxygen pressure systems shall minimize potential ignition sources through design practice, material selection, and functional testing. In the design of systems and the selection of components and materials, consideration shall be given to ignition mechanisms such as high flow regions; pneumatic shock (adiabatic compression); actuation components that result in impact loading, galling, or mechanically induced ignition; cavity resonance that can lead to ignition of trapped containments in blind passages; flow induced vibration; and failure of electric sensors or heaters that can cause arcing, sparking, or overheating. Piping and components shall be free of hydrocarbons or any foreign matter. The reactivity of oxygen with various materials is known to increase greatly with increased pressure. More comprehensive information on oxygen service is described in Chapter 5 of this Manual.

Hydrogen: Design and operation of systems for liquid hydrogen storage shall conform to requirements contained in NFPA 50B, "Standard for Liquefied Hydrogen Systems at Consumer Sites." Materials susceptible to hydrogen attack and hydrogen embrittlement shall not be used in hydrogen service. Materials that should be avoided include, but are not limited to, titanium, maraging steels, SA-517 or similar heat-treated steels, 400-series stainless steels, MIL-S-16216, and precipitation-hardened stainless steels. More comprehensive information on hydrogen service is described in Chapter 6 of this Manual, and NASA STD 8719.6, Safety Standard for Hydrogen and Hydrogen Systems.

7.10.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of cryogenic systems are required.

Cold-shock testing: New, altered, and repaired systems shall be cold-shock tested to verify the compatibility of material, equipment, and fasteners for cryogenic service. Prior to cold-shock testing, the vessel, components, and piping to be tested shall be inspected for proper assembly. Cold-shock testing shall be done in well-ventilated areas, preferably out of doors, to prevent asphyxiation of personnel. Such tests shall be conducted in accordance with the "Glenn Pressure System Testing Policy." (Section 7.20)

Pressure testing: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the "Glenn Pressure System Testing Policy" (Section 7.20).

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the cryogenic system. Monitoring cycles are defined in the Glenn Research Center’s Recertification Handbook based on size, pressure, volume, and fluid commodity. This monitoring helps ensure the integrity of the system. Users should verify current recertification status before placing a cryogenic system into service. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook".

7.10.4 Safety Considerations

Because of the nature of cryogenic systems, the following precautions should be taken:

a. Avoid contact with fluid or equipment cooled to cryogenic temperatures, since cryogenic systems contain fluids that are extremely cold.
b. The vapors of many cryogenic fluids are heavier than air; therefore avoid areas in unventilated spaces where low pockets of cryogenic vapor may accumulate.
c. Provide proper ventilation for all portable dewar fill stations. Low-oxygen alarms should be used if proper ventilation cannot be provided.
d. Vent relief devices to an area where no harm to personnel or equipment will result. Vent cans should be used wherever possible.
e. Adhere to guidelines for personal protective equipment, given in Chapter 15 of the Glenn Safety Manual.

7.11 STEAM SYSTEMS

7.11.1 Description

This section deals with the Lab-wide High Pressure Steam System, which supplies 100-psig (114.7 psia) saturated steam at 338° F for distribution to 44 buildings in the original central laboratory area. The Steam Plant does not supply the South Rocket Test Facility Area, the West Area, or the Development Engineering and Annex Buildings. These areas have independent steam-generation capabilities. The Steam Plant houses five conventional industrial boilers with a combined maximum steam output of 200,000 pounds/hour. The boilers can be fired with either gas or fuel oil.

Five main steam headers exit the Steam Plant. Four of the headers are routed in basements and below-grade trenches. Most of the building shutoff valves are located in a pit beside the building. Other buildings have shutoff valves inside the building at each pressure-reducing station. Main header isolation valves are located in trenches throughout the system.

7.11.2 Requirements

Design: Steam piping shall be designed in accordance with the ASME Code B31.1, "Power Piping." Particularly, the design shall address thermal expansion and flexibility of components and supports. Cast-iron valves shall not be used in the steam system. For any alterations or repairs to the piping system, standard weldable fittings or sections of similar pipe should be used rather than patches. Welded repairs require, at a minimum, visual examination, magnetic particle testing, and a hydrostatic test after completion. Such testing shall apply to any welding done to a pressure-retaining part, including anchor supports welded to the main steam line.

Materials: Metals selected must have allowable stress values as listed in Appendix A of the "Power Piping" Code and be in accordance with ASME SA, SB, or SFA specifications.

Relief device: Pressure-reducing stations shall include a pressure-relief device on the low-pressure side that can relieve all the capacity of the high-pressure side in the event that the reducing valve fails. Safety valves shall conform to the requirements of ASME B31.1.

7.11.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of the steam systems is required.

Pressure testing: Pressure testing of the high-pressure steam system shall be performed in accordance with the "Glenn Pressure System Testing Policy."(Section 7.20)

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the steam systems. Monitoring cycles are defined in the Glenn Research Center’s Recertification Handbook based on size, pressure and volume of systems. This monitoring helps ensure the integrity of the system. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.11.4 Safety Considerations

Some safety considerations for steam systems are as follows:

a. Because of the high temperatures associated with steam, care must be taken to avoid contact with steam, or pipes heated to steam temperatures.
b. Relief devices shall vent to an area where no harm to personnel or equipment will result. Discharge piping shall be added to relief devices where needed.

7.12 HIGH-PRESSURE GAS SYSTEMS

7.12.1 Description

High-pressure gas systems at Glenn are used for the storage and distribution of various gases, including argon, oxygen, hydrogen, nitrogen, and helium. A typical high-pressure gas system consists of a storage vessel or bottle in which the compressed gas is stored, pressure-relief devices, control valves, pressure gages, and distribution piping. These systems are generally used for research tests, valve actuation, purging, and welding.

7.12.2 Design Requirements

Stationary compressed-gas vessels shall be designed in accordance with the "ASME Boiler and Pressure Vessel Code," Section VIII. Portable bottles ("K" bottles) are part of Section 7.13 of this chapter (Mobile Equipment) and shall meet the DOT requirements of 49 CFR 100 to 185. The associated piping for all high-pressure gas systems shall be designed in accordance with ASME "Process Piping," B31.3.

7.12.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of high-pressure gas systems is required.

Pressure testing: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the "Glenn Pressure System Testing Policy."

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the high-pressure gas systems. Monitoring cycles are defined in the Glenn Research Center’s Recertification Handbook and are based on size, pressure, volume, and fluid. This monitoring helps ensure the integrity of the system. Users should verify current recertification status before placing a high-pressure gas system into service. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.12.4 Safety Considerations

Because of the high pressures associated with these systems, there is a possibility of high-energy projectiles impacting surrounding buildings, structures, and personnel in the event of an explosive rupture therefore; vessels should be located in remote areas if possible. In addition, since many of the compressed gases are flammable, sparks or sources of concentrated heat shall not be allowed to come in contact with the system; otherwise, the contained flammable gas might ignite at a leak in the system, or it may burn internally.

7.13 MOBILE GAS STORAGE EQUIPMENT

7.13.1 Description

The mobile gas storage equipment at the Glenn Research Center (compressed-gas cylinders, dewars, and liquid vaporizers) is used for storing and distributing compressed gases and cryogenic liquids. Design, fabrication, operation, and testing of mobile equipment is governed by 49 CFR 100 to 185 (DOT regulations). All materials used for construction of mobile vessels must be suitable for use with the commodities to be transported and must comply with 49 CFR.

7.13.2 Definitions

Service pressure: The authorized pressure marked on the container (49 CFR). For example, for compressed gas cylinder DOT 3AA2500, the service pressure is 2500 psig.

Cryogenic liquid: A refrigerated liquid having a boiling point lower than -130° F at 1 atmosphere (49 CFR).

Compressed gas: Any contained mixture having a pressure greater than 40 psia at 70° F or 104 psia at 103° F, or any flammable liquid having a vapor pressure exceeding 40 psia at 100° F (49 CFR).

7.13.3 General Requirements

Compressed gas cylinders: Requirements for compressed gas cylinders are as follows:

a. When compressed gas cylinders are connected to manifolds, the manifold and its related equipment shall be of proper design for the product it is containing, considering the temperature, pressure, and flow. Manifolds shall be designed in accordance with ASME B31.3, "Process Piping."

b. Each compressed gas cylinder shall be fixed at the manifold end of the vehicle, with provisions for thermal expansion at the other end.

Compressed gas cargo tanks (mobile tube trailers): The term "cargo tank" designates a compressed gas container, which is designed to be permanently attached to any motor vehicle. Such tanks must meet the following requirements:

a. Each compressed gas cargo tank must be equipped with at least one gauge as prescribed in 49 CFR. Additional gauges may be installed, but may not be used as primary controls for filling compressed gas cargo tanks.
b. Aluminum valves, piping, or fittings external to the jacket that retains lading may not be installed on compressed gas cargo tanks used to transport oxygen or cryogenic liquid.

Cryogenic liquid dewars: Dewars containing cryogenic liquids must conform to the following requirements:

a. A dewar designed for storing a cryogenic liquid shall be equipped with a pressure-control system that conforms to 49 CFR and that is designed and installed to prevent the dewar from becoming liquid full.
b. The jacket covering the insulation on a dewar used to transport oxygen or any flammable cryogenic liquid must be made of steel.
c. Aluminum valves or fittings with internal rubbing parts may not be installed on any dewar used to contain liquid oxygen.
d. Aluminum valves, piping, or fittings shall not be used on any dewar used to transport flammable cryogenic liquids.
e. No dewar shall be filled with a cryogenic liquid that is colder than the design service temperature of the container or that may combine chemically with any residue within the container to produce an unsafe condition.
f. Each cryogenic liquid dewar, except tanks filled by weight, must be equipped with at least one liquid level gauge as prescribed in 49 CFR. Additional gauges may be installed, but may not be used as primary controls for filling dewars.

Cryogenic liquid cargo tanks (mobile dewars): Mobile dewars must comply with the following requirements:

a. The jacket covering the insulation on a dewar used to transport oxygen or any flammable cryogenic liquid must be made of steel.
b. Aluminum valves or fittings with internal rubbing parts may not be installed on any mobile dewar used to transport cryogenic liquid oxygen unless the valve is anodized in accordance with ASTM B58-79.
c. Aluminum valves, piping, or fittings external to the jacket that retains lading may not be installed on mobile dewars used to transport oxygen, cryogenic liquid, or flammable cryogenic liquid.
d. A mobile dewar used to transport cryogenic liquid oxygen must be provided with a manhole as prescribed in 49 CFR.

e. Mobile dewars shall not be loaded with a cryogenic liquid that is colder than the design service temperature of the packaging or that may combine chemically with any residue in the packaging to produce an unsafe condition.

7.13.4 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of mobile equipment are required.

Pressure testing: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the "Glenn Pressure System Testing Policy" (Section 7.20).

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the mobile equipment. Monitoring cycles are defined in the Glenn Research Center’s Recertification Handbook and are based on size, pressure, volume, and fluid commodity. This monitoring helps ensure the integrity of the system. Users should verify current recertification status before placing the mobile equipment into service. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

Cylinders: Specific requirements apply to cylinder testing and recertification:

a. All NASA owned, leased, or loaned Department of Transportation/Interstate Commerce Commission (DOT/ICC) specification cylinders shall be inspected, retested, and maintained on a regular 5-year schedule in accordance with 49 CFR.
b. Cylinders due for periodic retest shall be tested and marked in conformance with the applicable requirements of 49 CFR.
c. Compressed-gas cylinders manufactured in accordance with 49 CFR shall be accepted or rejected for continued service on the basis of the expansion data obtained from hydrostatic testing and visual inspection of each cylinder in accordance with the Compressed Gas Association (CGA) Pamphlet C-5 "Cylinder Service Life-Seamless, Steel, High-Pressure Cylinders."
d. Regardless of the type of hydrostatic test method used, 49 CFR specifies that this periodic retest requires external and internal visual examination of the cylinder. It is recommended that these inspections be done prior to retest and that all rejected cylinders shall be condemned, destroyed and must leave the Center in unusable condition.
e. As specified in 49 CFR, the service life of a cylinder is terminated when a permanent expansion equaling 10% of the total expansion occurs during hydrostatic testing.
f. Gases other than liquefied, dissolved, poisonous, or flammable gases may be compressed so that the cylinder is charged to a pressure 10 % in excess of its marked service pressure, provided that the following conditions exist:
    - The elastic expansion has been determined at the last test by water jacket method to be less than the prescribed elastic expansion rejection limit. The

elastic expansion rejection limits for all 3A and 3AA specification cylinders are found in CGA Pamphlet C-5.
- The average wall stress and the maximum wall stress do not exceed the wall limitations of the material as prescribed by 49 CFR.
- The cylinders are equipped with frangible disk safety-relief devices (without fusible metal backing) that have a burst pressure not exceeding the minimum prescribed test pressure.
- An external and internal inspection at the time of retest showed that the cylinder is free of excessive corrosion, pitting, and dangerous defects.
- The cylinder is marked with a (+), indicating compliance with 49 CFR.

Mobile and Stationary Dewars (Cargo Tanks): Certain requirements apply to Mobile Dewar/Cargo Tank testing and recertification:

a. Each mobile dewar shall be tested and inspected at least every 5 years in accordance with the specification of 49 CFR.
b. Each mobile dewar must be subjected to a minimum internal pressure, as prescribed in 49 CFR, which can be hydrostatically or pneumatically generated.
c. Each mobile dewar shall be inspected for corroded areas, dents, evidence of leaking under test pressure, or other conditions that might render a tank unsafe, and shall be rejected if any such unsafe condition exists.
d. All piping, valves, and fittings on each mobile dewar shall be proved free from leaks at not less than the design pressure of the tank. In the event of replacement, all such piping, valves, and fittings shall be tested in accordance with 49 CFR.

Mobile and Stationary Dewars (Cargo Tanks): Certain requirements apply to Mobile Dewar/Cargo Tank testing and recertification:

a. Each mobile dewar shall be tested and inspected at least every 5 years in accordance with the specification of 49 CFR.
b. Each mobile dewar must be subjected to a minimum internal pressure, as prescribed in 49 CFR, which can be hydrostatically or pneumatically generated.
c. Each mobile dewar shall be inspected for corroded areas, dents, evidence of leaking under test pressure, or other conditions that might render a tank unsafe, and shall be rejected if any such unsafe condition exists.
d. All piping, valves, and fittings on each mobile dewar shall be proved free from leaks at not less than the design pressure of the tank. In the event of replacement, all such piping, valves, and fittings shall be tested in accordance with 49 CFR.

7.13.5 Safety Considerations

The Facility Engineering Division (FED) is responsible for reviewing and maintaining technical surveillance, inventory, and inspection of the mobile equipment used at Glenn.

General safety: In the interest of general safety, the following directives should be observed:

a. Since high-pressure air systems can be very dangerous when contaminated with oil, the distributor or user shall notify the owner about any condition that might permit a foreign substance to enter a container.
b. Containers and their appurtenances shall be maintained only by the container owner or his authorized personnel.
c. The prescribed markings or ownership markings shall be made in accordance with 49 CFR and shall not be removed or changed without owner authorization.
d. The user shall not change, modify, tamper with, obstruct, or repair pressure-relief devices.
e. Because cryogenic liquids and cold gases can cause frostbite injury on contact with the body, suitable precautions shall be taken to limit the possibility of injury when handling cryogenic liquids.
f. Cryogenic liquid dewars shall be stored and handled in well-ventilated areas to prevent excessive concentration of the gas.

Gas Cylinder Safety: The following are gas cylinder safety directives:

a. All cylinders that are charged with a compressed gas and transported shall be equipped with one (or more) pressure-relief device(s) that has been selected and tested in accordance with CGA Pamphlet S-1.1.
b. Each discharge for a safety-relief device on a cylinder containing a flammable compressed gas shall be arranged to discharge upward and unobstructed to the atmosphere.
c. The interconnection of several containers by manifolding is subject to restrictions detailed in 49 CFR. Where manifolding is authorized, each container shall be equipped with isolation valves and safety-relief devices as required by 49 CFR.

Dewar Safety: The following are dewar safety directives:

a. Each safety-relief device must have direct communication with the vapor space of the tank and be set at a pressure not to exceed the MAWP of the dewar.
b. No shutoff valve may be installed between the safety-relief device and the tank.
c. Each dewar shall be provided with a safety-relief device and shall be installed and maintained in accordance with 49 CFR. Each relief device must be installed so that the cooling effect of the contents during venting does not prevent effective operation of the device.
d. Each dewar in oxygen and flammable cryogenic-liquid service must be protected by two independent pressure-relief device systems that are not connected in series.

These devices must be selected in accordance with 49 CFR as follows:

a. The primary system should consist of one or more pressure-relief valves.
b. A secondary system should consist of one or more frangible disks or pressure-relief valves. For dewars carrying carbon monoxide, the secondary system must be composed of pressure-relief valves only.

7.14 REFRIGERATION SYSTEMS

7.14.1 Description

This section deals with the Freon system being used at Glenn to refrigerate the Icing Research Tunnel. This type of Freon used in this system is also known as Refrigerant R-134A, or tetrafluoroethane. It has a temperature of -15° F at atmospheric pressure.

The Freon refrigeration system consists of a storage tank to contain the liquid when the system is not in use, pressure-relief devices, pumps or compressors to pressurize or move the liquid, control valves, and distribution piping. All components and piping are heavily insulated.

7.14.2 Design Requirements

The storage tank shall be designed in accordance with ASME Code, Section VIII. Design considerations shall be given to thermal contraction and expansion strain in the tank and supports. The piping shall be designed in accordance with ASME B31.5, "Refrigeration Piping."

Metals selected for components shall remain ductile at liquid Freon temperatures. Alkali or alkaline-earth metals (aluminum, zinc, beryllium, etc.) are incompatible with Freon and must be avoided. Guidance on material selection for compatibility with liquid Freon may be found in ASHRAE 15, "Safety Standard for Refrigeration Systems."

7.14.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of the refrigerant system is required.

<u>Pressure testing:</u> Pressure testing of the refrigerant refrigeration system shall be performed in accordance with the "Glenn Pressure System Testing Policy" (Section 7.20)

<u>Recertification</u>: The Recertification Program calls for regular monitoring of all pressure components and piping of the refrigerant system. This monitoring helps ensure the integrity of the system. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.14.4 Safety Considerations

Leaks in a refrigerant system can be a source of illness or injury. If inhaled in large quantities, refrigerant vapor can cause heart irregularities and reduce the amount of oxygen that can be drawn into the lungs. Some safety considerations for working with refrigeration systems are as follows:

a. Since refrigerants are heavier than air, they will sink; therefore, care should be taken to avoid low elevations in unventilated spaces where pockets of refrigerants might accumulate.
b. Liquid refrigerants may cause frostbite, and it is a mild eye irritant, so avoid contact with skin and eyes.
c. Refer to Loss Prevention Data Sheet 7-13, "Mechanical Refrigeration," published by FM Global Resource Collection, for refrigeration systems safeguards.
d. Refer to ASHRAE Standard 15, published by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., for refrigeration system design and safety requirements.
e. Refrigerants, which will replace freon, are hazardous and require special safety precautions.

7.15 WIND TUNNELS

7.15.1 Description

Wind tunnels are structures that direct airflow over test objects, such as model aircraft, engines, wings, and rockets. Airflow can be produced by fans, compressors, or gas compressed into storage tanks. The air flows through the nozzle section, which increases the velocity to a desired speed. The test section contains the test object, which is connected to instrumentation that measures and records airflow, aerodynamic forces, and other parameters. A diffuser section reduces the air velocity before exhausting the air to the atmosphere or returning it to the fan or compressor. Depending on the tunnel, auxiliary systems such as refrigeration, high-pressure gas, compressed air, and others may be present.

Wind tunnels are usually designated by the size of the test section and the air velocity through the test section. There are six wind tunnels at Glenn, ranging from a 1 X 1 foot test section to a 10 X 10 foot test section. The 1 X 1 foot tunnel, which is in Building 37, uses the Combustion Air System as its source of air. It is a once-through tunnel that exhausts to the atmosphere.

The 8 X 6 supersonic tunnel and the 9 X 15 tunnel are located in two legs of the same tunnel loop. The 8x6 can be operated in aerodynamic mode, with air continuously circulating through the tunnel, or in propulsion mode, with airflow being exhausted to the atmosphere. The 9 x 15 operates only in aerodynamic mode, with air speeds of about 300 miles per hour. Large axial-flow compressors provide airflow for both tunnels; dryers, heaters, and coolers maintain the air at desired test conditions. Most of the exterior structure of this tunnel is constructed of reinforced concrete.

The 10 X 10 Foot Supersonic Wind Tunnel can be operated in aerodynamic or propulsion mode. Mach numbers in the tunnel can be adjusted from 2.0 to 3.5. The exterior structure of this tunnel is mostly steel. Two sets of compressors provide airflow; dryers, heaters, and coolers allow adjustment to desired test conditions.

The Icing Research Tunnel is a World-War-II-vintage tunnel that is a National Historic Landmark. In 1987, much of the tunnel system was modernized. In 1999 the Icing Tunnel experienced another phase or reconstruction began, which included replacement of a 50-year old heat exchanger, new turning guide vanes and some modification of the tunnel structure to accommodate the more modern components. This construction program was completed in July 2000. It has a 6 X 9 foot test section where speeds of up to 300miles per hour are attainable. The tunnel operates with the refrigeration system and a set of spray nozzles to produce any desired icing conditions in the test section. A large wooden propeller provides airflow. The exterior structure of this tunnel is light-gage steel with an exterior blanket of insulation.

Plum Brook Station has a Hypersonic Tunnel Facility. This is a blowdown tunnel that uses a mixture of heated nitrogen and oxygen to simulate flow of air at desired Reynolds numbers. The tunnel exhausts directly to the atmosphere, aided by a steam jet ejector. It can operate at Mach numbers ranging from 3 to 7. Support systems for this tunnel are extensive and include high-pressure nitrogen, oxygen, and hydrogen systems and a large 125-psig steam system.

7.15.2 Design Requirements

Although there is no specific code for the design of wind tunnels, there are codes for the design of tunnel components:

a. Pressurized tunnels and piping shall be designed in accordance with ASME Code, Section VIII and ASME B31.3. Relief protection shall be provided in accordance with Section 7.9.2 of this chapter.
b. Low-pressure tunnels shall be designed in accordance with standard structural engineering practices. Guidance on structural standards may be found in American Welding Society standard AWS D1.1/D1.1M.
c. Thermal contraction and expansion effects shall be addressed during design of both high-pressure and low-pressure tunnels, because of the low temperatures obtained by high-velocity flow.
d. Low-pressure tunnels shall be evaluated to determine conformance to national consensus standards such as AWS D1.1/D1.1M. As a minimum, the hoop stress associated with major structures shall be less than one-fourth of the minimum specified ultimate tensile strength of the material in the tunnel. If material properties are unknown, conservative assumptions or material samples may be used to establish tensile strength.

e. Materials selected for the tunnel shall be appropriate for the conditions to which the tunnel is exposed, both internally, as a result of operating modes, and externally, as a result of the tunnel's location.

7.15.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of wind tunnels are required.

Modes of potential failure, including cyclic fatigue due to pressure, temperature, or vibration, as well as corrosion, erosion, or other inservice failure mechanisms, shall be identified and evaluated. The primary objective is to identify those areas that do not meet national consensus standards. Areas that are not in accordance with these standards can be addressed with respect to their impact on safety and reliability.

<u>Pressure testing:</u> Pressure testing of wind tunnels shall be performed in accordance with the "Glenn Pressure System Testing Policy." The Glenn Research Center Recertification Program has established the following inspection methods for the 8X6, 10X10, and Icing Research Tunnels. Inspections consist of visual, random ultrasonic and random weld inspections (magnetic particle or dye penetrate). Additional selective nondestructive testing may be conducted as deemed appropriate by Pressure Systems Manager.

<u>Recertification:</u> The Recertification Program calls for regular monitoring of all pressure components and piping of wind tunnels. This monitoring helps ensure the integrity of the system. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.15.4 Safety Considerations

Some important wind tunnel safety precautions are as follows:

a. The primary safety concern with regard to wind tunnels is the generation of missiles that can injure personnel and damage models or equipment. Therefore, all models and test instrumentation shall be secured before operation of the tunnel.
b. Because of the high velocities and noise created by an operating wind tunnel, appropriate warning signs and indicators shall be installed around the tunnel.
c. Blow down or exhaust portions of tunnels shall discharge into an area where no hazard to personnel or equipment will result.
d. Since some tunnels are remotely operated, evacuation signals and interlocks shall be used prior to operation, to ensure that all personnel are in safe areas.

7.16 COMPRESSED-AIR SYSTEMS

7.16.1 Description

There are at least five different compressed-air systems at NASA Glenn: a 3000-psig air system for the 10 x 10 Foot Supersonic Wind Tunnel; 450-psig and 40-psig combustion air systems in the Engine Research Building (ERB); a 125-psig service air system, in the ERB; and a 150-psig combustion air system in the Propulsion Systems Laboratory Building. The combustion air from compressors in Buildings 5 and 64 is supplied to 23 different buildings that are interconnected by a series of lines ranging from 10 through 54 inches in diameter.

There are 48 air-compressor/receiver tank units throughout Glenn. Thirty of these units are connected to the laboratory service air system. The remaining 18 are stand-alone units. The compressors range in size from 1/6 to 15 horsepower, and the pressure tanks range in capacity from 5 to 150 gallons.

7.16.2 Requirements for Piping

<u>Design:</u> Compressed-air piping shall be designed in accordance with ASME B31.3, "Process Piping." Particularly, the design shall address thermal expansion and flexibility of components and supports. Standard weldable fittings or sections of similar pipe should be used for any alterations or repairs to the piping system. Welded repairs require at least a visual examination, magnetic particle testing, and a hydrostatic test after completion. This shall apply to any welding done to a pressure-retaining part, including anchor supports welded to a compressed-air line. See sections 7.6 and 7.7 for welding procedures.

<u>Materials:</u> Metals shall be selected that have allowable stress values as listed in Appendix A of ASME B31.3, "Process Piping" and that are in accordance with ASME SA, SB, or SFA specifications.

<u>Safety device:</u> Pressure-reducing stations shall include safety or relief devices on the low-pressure side that can relieve all the capacity of the high-pressure side in the event that the reducing valve fails to open. Safety valves shall conform to the requirements of Section VIII of the "ASME Boiler and Pressure Vessel Code."

7.16.3 Requirements for Compressed-Air Vessels

<u>Design:</u> Compressed-air vessels shall be designed in accordance with the ASME Code, Section VIII. Particularly, the design shall address thermal expansion between vessel, piping, and supports. Vessels should have manufacturer tags or clearly exposed markings to ensure that operating pressures and temperatures do not exceed the design range values.

Materials: Metals shall conform to a specification in the "ASME Boiler and Pressure Vessel Code," Section II. Allowable stress values are given in Section II, Part D. Materials used for nonpressure parts, and parts attached to the vessel, shall conform to the requirements of Section VIII.

Safety device: Safety devices shall conform to the requirements of Section VIII of the "ASME Boiler and Pressure Vessel Code." Discharge piping shall have a minimum number of elbows so as not to constrict discharge flow.

7.16.4 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of the compressed air systems are required.

Pressure testing: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the Glenn Recertification Program administered by the Facilities Division

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the compressed-air systems. Monitoring cycles are defined in the Glenn Research Center's Recertification Handbook based on size, pressure, and volume. (More information may be found in section 7.13.4) This monitoring helps ensure the integrity of the system. Users should verify current recertification status before placing a compressed-air system into service. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.16.5 Safety Considerations

In the interest of safety, the following precautions should be taken:

a. Vent relief devices to an area where the air will cause no harm to personnel or equipment. Add discharge piping to relief devices where needed.
b. Do not mount the air compressor and drive on an air receiver tank because the vibrations may crack welds, thereby causing a tank explosion.
c. Drain water from the tank frequently; this will prevent internal corrosion from thinning the tank shell.

7.17 ALTITUDE EXHAUST SYSTEM

7.17.1 Description

This section deals with large systems that operate at pressures below atmospheric. The Altitude Exhaust System at Glenn consists of large-diameter piping that enables altitude condition simulation in test cells and serves as a means of exhausting engine combustion products. The system, which contains spray coolers and fintube heat exchangers, is exhausted by blowers located in several buildings.

7.17.2 Design Requirements

Several aspects of the Altitude Exhaust System require special attention. The "ASME Boiler and Pressure Vessel Code" and ASME B31.3 "Process Piping" both require that vessels and components be designed for full internal vacuum or 15-psig external pressure. Since large-diameter piping is associated with the Altitude Exhaust System along with large coolers and heat exchangers, external reinforcing structures are often required. The internals of coolers and heat exchangers often have integral structural bracing to reinforce the walls of the vessel.

Because exhaust products are cooled with direct water spray, the interior of the Altitude Exhaust System is directly exposed to highly corrosive conditions. For this reason, generous corrosion allowances must be included in the design of vessels and components.

7.17.3 Recertification

To ensure the safety of personnel and equipment, recertification of the Altitude Exhaust System is required. No pressure testing of any segment of the Altitude Exhaust System shall be performed without consulting with the Recertification Manager of the Facilities Division.

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the Altitude Exhaust System. This monitoring helps ensure the integrity of the system. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook."

7.17.4 Safety Considerations

For safe operation of the Altitude Exhaust System, note the following:

a. The Altitude Exhaust System moves very large volumes of air; although the pressures are low, this amount of air moving through the system can cause damage if a failure occurs. The flat-sided exhaust coolers, because of their shape, are particularly vulnerable to weld failure from vibration and to internal corrosion. External reinforcement of vacuum vessels, piping, and components shall be inspected on a regular basis.
b. Internal corrosion can be a significant problem in this system. Provisions shall be made for proper drainage and inspection of wall thickness of vessels, piping, and components.

7.18 SPECIALTY SYSTEMS

7.18.1 Description

Systems included in this category are generally small package units used for such purposes as chemical injection or lubrication. Examples of specialty systems are boiler feedwater treating systems, cooling water treatment systems, and compressor lube and seal oil consoles. The fluids in these systems include biocides, strong acids and bases, and specialized oils, among others. System pressure-containing components may include nonmetalic materials.

7.18.2 Design Requirements

Specialty systems shall be designed in accordance with a national consensus code or shall be certified in accordance with Underwriter's Laboratories or other nationally recognized testing laboratories.

Special attention shall be paid to materials used in specialty systems, since the system fluid may have peculiar material requirements. The suppliers of the system hardware and the fluid should be consulted to ensure compatibility between the fluid and all pressure-containing, sealing, and nonmetallic components.

7.18.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of specialty systems are required.

Pressure testing: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the "Glenn Pressure System Testing Policy"(Section 7.20) and/or with manufacturer's specifications and instructions as applicable.

Recertification: The Recertification Program calls for regular monitoring of all pressure components and piping of the specialty systems. This monitoring helps ensure the integrity of the system. Users should verify current recertification status before placing a specialty system into service. All recertification activities shall be performed in accordance with the "Glenn Pressure Vessel/System Recertification Handbook" and/or with manufacturer's specifications and instructions as applicable.

7.18.4 Safety Considerations

The following points must be considered for safe operation of specialty systems:

a. Unusual fluids may be contained in a specialty system. To alert personnel to potential hazards, all specialty systems shall be labeled in accordance with OSHA regulations 29 CFR 1910.1200.

b. Specialty systems may operate at high pressure or temperature.
c. Since specialty systems are unique, the manufacturer or supplier shall provide detailed safety, maintenance, testing, and inspection information. This information shall be conveniently accessible to all personnel who may work with the system.

7.19 HYDRAULIC SYSTEMS

7.19.1 Description

Hydraulic systems are used to move or control mechanical hardware. These systems are generally package systems with a hydraulic-fluid reservoir, filters, a pump, relief devices, switching valves, and a fluid system that usually has flexible hoses. Flexible hoses are required because of the motion caused by the hydraulic system. The pressures in a hydraulic system are very high, on the order of thousands of pounds per square inch. Large forces are produced by hydraulic actuators, and the systems are often remotely controlled.

7.19.2 Design Requirements

Pressure vessels in hydraulic systems shall meet the requirements of "ASME. Boiler and Pressure Vessel Code," Section VIII, Division I or II. Piping systems shall meet the requirements of ASME B31.3, "Process Piping." Compliance with applicable standards of The Hydraulic Institute is required.

7.19.3 Testing and Recertification

To ensure the safety of personnel and equipment, testing and recertification of hydraulic systems are required.

<u>Pressure testing</u>: Pressure testing of new, altered, and repaired systems shall be performed in accordance with the "Glenn Pressure System Testing Policy."(Section 7.20)

7.19.4 Safety Considerations

To safely operate hydraulic systems, note the following:

a. The actuating system shall be locked out and disabled before any work is performed on hydraulically actuated mechanisms.
b. Large forces are produced by hydraulic systems; therefore, personnel shall remain a safe distance away from active hydraulic systems.
c. Moving portions of hydraulic systems shall be repaired or replaced immediately if any wear or leakage is observed. These portions include hoses and cylinder seals.
d. Many hydraulic fluids are flammable; they shall be handled in accordance with safe practices for flammable fluids.

7.20 PRESSURE SYSTEM TESTING POLICY

7.20.1 Applicability

This Pressure System Testing Policy defines testing requirements for existing and new ground-based pressure vessels and piping systems at NASA Glenn Research Center. NASA requires compliance with national consensus codes and standards to maintain the highest degree of safety for personnel and property. Glenn recognizes the unique nature of the research programs conducted in the laboratories, so this policy allows for controlled departures from the strict requirements of national codes when sufficient justification exists and when safety of personnel is not compromised. Any deviation or departure from consensus standards must be submitted to the Process Systems Safety Committee or the cognizant Area Safety Committee. Variance requests to national consensus standards and the Glenn Safety Manual require final approval of the Authority Having Jurisdiction and the Executive Safety Board.

Cold-shock testing must be performed on all systems in cryogenic service. Before any pressure is applied to the system, it must be chilled to cryogenic temperatures and observed for leakage. After successful completion of the cold-shock test, a pressure test is performed.

All pressurized systems at Glenn must be pressure tested. A pressure test is the last test performed on a system before the system is put into service. The purpose of the test is to verify structural integrity and pressure tightness. With appropriate nondestructive examination (NDE), the pressure test gives assurance that potential hazards to personnel and property are at a minimum.

<u>Systems requiring testing</u>: A pressure test is required to verify the integrity of all newly installed or altered pressure vessels and piping systems at Glenn Research Center. At the discretion of the design engineer or the appropriate Safety Committee, repaired systems may be required to undergo a pressure test. In the following situations a pressure test is required:

a. Installation of a new pressure system that uses either new or reused components.
b. Alteration of an existing system (The National Board Inspection Code defines an alteration as any change that affects the pressure-containing capability of the system. Some nonphysical changes, such as an increase in the maximum allowable working pressure or design temperature, are considered alterations. A reduction in minimum temperature such that additional mechanical tests of system materials are required is also considered an alteration.)
c. Physical relocation of a stationary pressure vessel, if damage to the pressure vessel is suspected
d. Periodic recertification of a pressure vessel or piping system in accordance with the "Glenn Pressure Vessel/System Recertification Handbook"
e. Repair of an existing pressure system if the system engineer or the cognizant Safety Committee requires it (The National Board Inspection Code defines a

repair as any work necessary to restore a system to a safe operating condition, provided there is no deviation from the original design.)

Systems excluded: This pressure testing policy does not apply to the following:

Mobile pressure vessels: Compressed gas cargo tanks (mobile tube trailers) and cryogenic liquid cargo tanks (mobile dewars) are classified as mobile pressure vessels. (See 7.13.3 for definitions) These vessels fall within the cognizance of DOT requirements in 49 CFR. The Code of Federal Regulations requires periodic pressure tests and specifies allowable repairs.

Mobile pressure vessels designed and fabricated in accordance with DOT regulations should not normally be specified for permanent installation in pressurized systems. If a DOT-designed pressure vessel is installed as a stationary system, it shall be rerated in accordance with the ASME "Boiler and Pressure Vessel Code."

Unique piping systems: Piping systems for certain commodities are designed to specific ASME piping codes. These codes have requirements that relate to those commodities, including pressure test requirements. Some specific codes applicable to Glenn are ASME B31.2, "Fuel Gas Piping"; B31.5,"Refrigeration Piping and Heat Transfer Components"; B31.8, "Managing System Integrity of Gas Pipeline"; and B31.9, "Building Services Piping Code."

For such piping systems, the pressure test requirements of the appropriate code shall be used directly.

Exceptions to this pressure test policy and acceptable alternate testing methods are discussed in Section 7.15.3.

7.20.2 Reference Codes and Standards

NASA documents: The following NASA documents provide guidance on pressure system testing policy:

- Glenn Safety Manual
- NASA Glenn Pressure Vessel/System Recertification Handbook
- NPR 1700.6A, "Guide for Inservice Inspection of Ground Based Pressure Vessels and Systems"
- NPR 8710.5A, NASA Safety Policy for Pressure Vessels and Pressurized Systems.

National consensus codes and standards: The following national codes provide guidance on pressure system testing policy:

- 49 CFR, Part 173.34, "Qualification, Maintenance and Use of Cylinders"

- NB-23, "National Board Inspection Code," National Board of Boiler and Pressure Vessel Inspection
- ASME B31.1, "Power Piping"
- ASME B31.3, "Process Piping"
- ASME Boiler and Pressure Vessel Code, Section VIII, "Rules for Construction of Pressure Vessels," Division I and Division II
- Compressed Gas Association Pamphlet C-1, "Methods for Hydrostatic Testing of Compressed Gas Cylinders"

7.20.3 General Testing Requirements

This pressure system testing policy prescribes a hydrostatic pressure test as the baseline requirement for pressure testing of a pressure vessel or pressurized system. Before any pressure test is started, appropriate nondestructive examination of the system shall be performed in accordance with the applicable code. This will minimize potential hazard or delay during the pressure test. In addition, all systems for cryogenic service shall be cold-shock tested before being pressure tested. The hydrostatic pressure test shall be conducted in accordance with the applicable consensus code. The unique nature of the research conducted at Glenn may require exceptions to code requirements. To allow for these exceptions and to create a policy that meets the intent of the applicable code, a hierarchy of required pressure tests is established as follows:

TEST	**TEST METHOD**
Cold-shock test	For cryogenic systems only; expose system to liquid nitrogen temperatures (-320° F) to verify compatibility of design and materials for cryogenic service
Primary pressure test	An optional low-pressure gas-leak test followed by a hydrostatic pressure test conducted in accordance with the applicable code.
Alternate pressure test 1	An optional low-pressure gas-leak test followed by a pneumatic or combination hydrostatic/pneumatic pressure test conducted in accordance with the applicable code.
Alternate pressure test 2	An optional low-pressure gas-leak test followed by a pressure test at operating pressure, combined with restrictions for operation and supported by additional analysis or other tests.

This policy provides instructions to determine when to request the use of an Alternate test. Pressure testing is done to verify the structural integrity of a vessel or piping system. The ultimate benefit is <u>to ensure personnel safety</u>; therefore, <u>considerations of time or funding are not sufficient reasons to request use of the alternate test methods or to waive any test requirements.</u>

If a system will never operate above 10% of its maximum allowable working pressure, and if relief protection is provided to limit operating pressure accordingly, then Alternate pressure test 2 may be acceptable. This is subject to approval of the appropriate Safety Committee and the GSO.

With the exception of low-pressure gas-leak tests (Section 7.20.6), none of the aforementioned tests shall be conducted until a written procedure incorporating appropriate safety procedures has been approved by the cognizant Safety Committee.

Different terms exist for the maximum allowable pressure in a pressure system. ASME Code, Section VIII, Division I uses "maximum allowable working pressure" (MAWP), whereas Division II uses "design pressure." ASME Piping

Codes also use "design pressure," but DOT requirements refer to "service pressure." This document uses MAWP to describe the maximum pressure at which a component or system is designed to operate, unless referring to a specific code.

7.20.4 Pressure System Testing Requirements

<u>Primary pressure test-Hydrostatic pressure test</u>: Before any pressure tests are considered, all new or altered cryogenic pressure vessels and piping systems shall be cold-shock tested (Section 7.20.5). Furthermore, before any hydrostatic pressure test is done, a low-pressure gas-leak test is recommended for detecting gross leaks.

All high points in the system shall be provided with valves to bleed possible air pockets while the system is being filled with test fluid. If the system cannot be vented, safety measures equivalent to those taken with a pneumatic test must be implemented.

During application of hydrostatic pressure, nonessential personnel shall be restricted from the test area and the area shall be barricaded or patrolled to enforce such restriction. Test personnel must take shelter behind structures, walls, or proper supports, and take precautions against the potential danger from fluid leakage.

<u>Testing new vessels/systems</u>: New stationary pressure vessels shall be designed, fabricated, and installed in accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Division I or Division II, latest edition. This is a minimum requirement. The code requires a hydrostatic test at 1.3 times maximum allowable working pressure (MAWP) for Division I vessels, and a hydrostatic test of 1.25 times design pressure for Division II vessels. Pressure vessels tested at the fabricator's shop need not be retested after installation unless damage or mishandling during shipment is suspected.

New piping systems shall be designed, fabricated, and installed in accordance with ASME B31.1 "Power Piping" (for steam piping) or ASME B31.3 "Process Piping" (for other pressure piping), latest edition. These codes require a hydrostatic test of 1.5 times design pressure.

When test temperature is different from design temperature, test pressure shall be adjusted by multiplying MAWP by the ratio of the allowable stress for the test temperature to the allowable stress for the design temperature. This applies to both pressure vessels and piping systems.

For Division I vessels, $P_{test} = [1.3] * [MAWP] * [S_{test} / S_{design}]$

For Division II vessels, $P_{test} = [1.25] * [P_{design}] * [S_{test} / S_{design}]$

For B31.1 piping, and B31.3 piping, $P_{test} = [1.5] * [MAWP] * [S_{test} / S_{design}]$

If the test pressure adjusted for temperature would produce a stress in excess of yield strength at test temperature, the test pressure should be reduced to the maximum pressure that will not exceed yield strength at test temperature.

Testing existing stationary pressure/piping systems: Existing pressure/piping systems or components require a hydrostatic pressure test before being returned to service if any of the following apply:

a. They have been altered. In such cases, test the system before returning it to service.
b. They have been physically moved or relocated, and damage or mishandling is suspected. Relocation should be witnessed by a NASA representative with authority to decide if any damage occurs.
c. They are pressure systems or components that have been repaired by welding and the systems engineer or cognizant Safety Committee deems such a test necessary.
d. They are stationary piping systems that have been altered or repaired by welding.

Piping and manifolds on mobile equipment such as DOT compressed-gas-cylinder trailers shall be tested in the same manner as stationary systems.

<u>Alternate test 1-Pneumatic pressure test:</u> Permission to perform a pneumatic test instead of a hydrostatic test may be requested if any of the following conditions apply:

a. The system is so designed or supported that it cannot safely be filled with water.
b. The system cannot be dried and is to be used in a service where traces of the testing liquid cannot be tolerated. This must be clearly substantiated.
c. A hydrostatic test would damage linings or internal insulation.

<u>Pneumatic pressure tests are significantly more hazardous than hydrostatic tests because of the large amount of energy contained in the compressed gas.</u> Precautions to be taken during a pneumatic pressure test may be found in Pneumatic Pressure Testing Guidelines.

<u>**A pneumatic pressure test that exposes personnel to potential hazard is unacceptable and will not be approved**</u>. If safeguards can be implemented to eliminate

exposure of personnel to pneumatic test hazards, and if the risk to property is shown to be acceptable, then a pneumatic pressure test may be considered.

Combination hydrostatic/pneumatic pressure tests are as hazardous as pneumatic tests; therefore, identical precautions shall be employed. The two-man buddy system shall always be used for pneumatic pressure testing.

Before any pressure tests are considered, all new or altered cryogenic pressure vessels and piping systems shall be cold-shock tested.

Furthermore, a low-pressure gas-leak test shall be performed before a pneumatic pressure test is considered.

Pneumatic test pressures: The pneumatic test pressure for an ASME Code, Section VIII, Division I pressure vessel shall be equal to at least 1.1 times the MAWP. Test pressure for a Division II vessel shall be equal to at least 1.15 times the design pressure.

For steam piping designed to ASME B31.1, the pneumatic test pressure for a piping system shall be equal to at least 1.2 times the system design pressure. Piping systems designed to ASME B31.3 shall be pneumatically tested to at least 1.1 times design pressure.

When test temperature is different from design temperature, test pressure shall be adjusted by multiplying MAWP by the ratio of the allowable stress for the test temperature to the allowable stress for the design temperature. This applies to both pressure vessels and piping systems.

For Division I vessels, $P_{test} = [1.1] * [MAWP] * [S_{test} / S_{design}]$

For Division II vessels, $P_{test} = [1.15] * [P_{design}] * [S_{test} / S_{design}]$

For B31.1 piping, $P_{test} = [1.2] * [MAWP] * [S_{test} / S_{design}]$

For B31.3 piping, $P_{test} = [1.1] * [MAWP] * [S_{test} / S_{design}]$

If the test pressure adjusted for temperature would produce a stress in excess of yield strength at test temperature, the test pressure must be reduced to the maximum pressure that will not exceed yield strength at test temperature.

Hazards of pneumatic testing: The following paragraphs illustrate some hazards associated with pneumatic testing. Personnel attempting a pneumatic test of any system should be aware of these potential hazards:

a. Fragmentation into shrapnel will result if the part under test breaks up. Since the shrapnel will travel at high velocity for long distances, the likelihood of injury to unprotected personnel or equipment is very high.

b. An explosive noise will result from a large rupture, whereas noise of extended duration will result from a small-orifice failure. By reflex action from the sudden noise, personnel in the nearby area could expose themselves to injury. Another hazard to consider is the cutting action of a high velocity, small-orifice air leak.
c. A pressure wave or pulse could develop from a gross rupture, presenting a hazard to personnel and possible damage to surrounding equipment and structures.
d. Equipment motion resulting from a gross rupture can cause whip action from failure of a flexible pipe or hose, unless the system is securely fastened. In addition, a severe structural failure of a light-weight container or vessel could cause the part to act as a projectile, propelled by the resulting discharge force. Therefore, before any pneumatic test is conducted, the parts shall be securely fastened to prevent hazardous movement.

Brittle materials shall not be subjected to pneumatic pressure tests. A brittle material is one that has either (1) less than 10% elongation in standard tensile tests or (2) a ductile-to- brittle transition temperature (as indicated by Charpy impact tests) that is above the test temperature. Some commonly used brittle materials are glass, cast iron, and most high strength alloys.

Safety of personnel, buildings, and equipment are of primary concern during a pneumatic pressure test. During the application of pneumatic pressure, nonessential personnel shall be located a safe distance from the test area.

Appendix A of this chapter shows the recommended method for determining the restricted distance for pneumatic tests. The restricted distance is based on the distance where blast overpressure will equal 0.5 pound per square inch; this level of overpressure may shatter glass windows. Protection of buildings and major structures shall also be considered if they are inside the exclusion area. The restricted area shall be barricaded or patrolled to control movement of all nonessential personnel in the area.

<u>Alternate pressure test 2</u>: A hydrostatic test is not feasible because of conditions listed under alternate test 1, and the hazard to property of a pneumatic test is excessive, a request may be made to substitute an operating pressure test. Such a request must be accompanied by restrictions for operating the vessel and supported by additional analyses or other tests.

Before test pressure is applied, appropriate NDE must be performed, analysis of suspect areas must be completed, and operational restrictions must be developed. Repairs resulting from NDE and analysis shall be completed before the pressure test.

<u>Analysis</u>: Examples of analyses that may be required are:

a. Failure modes and effects analysis
b. Fracture mechanics analysis to determine critical crack size and crack growth characteristics
c. Finite element analysis of areas suspected of having high stress concentration

d. Fatigue analysis of highly stressed areas
e. Piping flexibility analysis

Analyses shall be available for review by the appropriate Safety Committee or its designee. All analysis results shall show that the vessel is not hazardous to personnel at normal operating conditions.

Any pressure test that exposes personnel to potential hazard is unacceptable and will not be approved. If safeguards can be implemented to eliminate exposure of personnel to pressure test hazards, and if risk to property is shown to be acceptable, then alternate test 2, a pressure test at a pressure of not less than 100% of operating pressure, may be considered with appropriate safety committee and GSO approval.

The operating pressure test is similar to a pneumatic pressure test, except that test pressure is raised only to operating pressure, and the system is closely examined after a bubble leak-check solution is applied at operating pressure. Refer to the Pneumatic Pressure Test Guidelines (Section 7.20.8) for details of developing a test procedure.

Operating pressure test shall not be performed until the nondestructive examinations and repairs have been successfully completed, all analyses judged acceptable and all operational restrictions implemented. In addition, all new or altered cryogenic pressure vessels and piping systems shall be cold-shock tested (Section 7.20.5) before any pressure tests are considered. A low-pressure gas-leak test (Section 7.20.6) shall be performed before an operating pressure test is considered.

Consideration shall be given to performing hydrostatic tests (as described in Section 7.20.7) on components or sections of the piping system. If all components or sections successfully pass the hydrostatic test, then this operating pressure test will be addressing only small untested portions of the system and the potential hazards of testing the system will be significantly reduced.

The operating pressure test consists of gradually raising pressure to operating conditions in 10% steps, and closely examining all weld joints and pressure boundary attachments for leakage at each pressure step. Close examination shall not be done when pressure is more than 100% of system operating pressure.

<u>Examination:</u> Welds and components that have not been subjected to hydrostatic or pneumatic leak tests shall be examined as follows:

a. Circumferential and longitudinal groove welds shall be 100% radiographed in accordance with the "ASME Boiler and Pressure Vessel Code," Section VIII, Division I or II.
b. All untested components and welds, including structural attachment welds, not covered in paragraph (a) shall be examined by the magnetic particle method. Materials that are not magnetic shall be tested by the liquid penetrant method.

c. Results of the foregoing tests shall be interpreted in accordance with the ASME code, Section VIII, Division I or Division II; or ASME B31, "Process Piping," whichever applies.
d. Welds not meeting acceptance criteria shall be repaired in accordance with ASME code and reinspected by the same method that detected the rejectable indication. Components not meeting acceptance criteria shall be repaired or replaced, and then reinspected.

Restrictions for operation may be required to ensure safe operation of the system. These restrictions shall be developed for use both during the pressure test and during subsequent normal operation of the system. The restrictions may include physically isolating the system with blast walls, removing all personnel from a defined area when the system is pressurized, or placing the vessel in a remote location. Permanent signs and barriers should be considered. Other precautions may be required.

7.20.5 Cold-Shock Testing

Systems requiring cold-shock testing: All vessels or lines designated for cryogenic service shall be subjected to a standard cold-shock test as described in this section. If a problem arises from following these procedures, the cognizant Safety Committee shall be consulted.

Sequence of cold-shock test: A cold-shock test is the initial test in the sequence for testing of cryogenic systems. It is to be performed before any pressure test is considered.

Fluids for cold-shock test: The recommended fluid for cold-shock testing is liquid nitrogen (LN2). Alternate fluids, for special cases only, are nitrogen or helium gas cooled to at least -150° F by an LN2 heat exchanger.

CAUTION - When using LN2 in the pressure testing procedures for LH2 systems, be aware of the weight and temperature differences between the two fluids.

Purpose of cold-shock testing: The purpose of cold-shock testing is to verify compatibility of materials, equipment, and fasteners for cryogenic service. Cold-shock testing of recommended cryogenic materials at LN2 temperatures (-320° F) will produce at least 93% of the total thermal contraction that would be obtained with liquid hydrogen (-423° F) and liquid helium (-452 °F). This contraction in the system being tested may reveal defects such as brittle fracture, physical distortion, and incompatibility of materials.

The following precautions will help prevent injury to personnel and failure of the system:

a. Inspection: The vessel, component, or piping system shall be inspected for correct assembly, weld quality, correct torque on threaded fasteners, and trapped liquids.

The pressure of liquids trapped in cavities and frozen by cryogenic temperatures may cause failure of the system.

b. Personal protection: The principal hazards of cold-shock testing are the extremely low temperatures involved and the potential for asphyxiation. All personnel shall be dressed in personal protective equipment before chilling the system. Gloves that are relatively impenetrable and loose fitting shall be worn for handling LN2 equipment or LN2-cooled parts. Handlers of LN2 shall also wear a face shield that will stop splashes from all directions. An apron of nonabsorbent material shall be worn when splashing is a possibility. Trousers shall be cuffless and worn outside leather high-top shoes.
c. Ventilation: To prevent asphyxiation of personnel, cold-shock testing shall be done out-of-doors or in adequately ventilated areas.
d. Procedure: The preferred cold-shock testing method is immersion, but if such is not possible, the cold flow method may be used.
e. Immersion: Whenever possible, the system shall be completely immersed in an open LN2 container fabricated from material approved for use with cryogenic fluids. The system shall be immersed slowly to prevent LN2 splashing.
f. Cold flow: If the configuration of a system prohibits complete immersion in LN2, flow low-pressure LN2 (as close to atmospheric pressure as possible) through the system or fill it with an LN2-cooled gas.

CAUTION - If the system being cold-shock tested has been designed for a cryogen other than LN2 (e.g., LH2), the design engineer shall determine the amount of LN2 to be used so as not to overload the structure with heavier fluid.

The piping that runs from the LN2 container to the system being cold shock tested shall be as short and direct as possible. The initial flow of LN2 should be established directly into the system under test, rather than through a precooled line, so as to provide maximum temperature induced shock.

Adequate venting capacity of the system shall be ensured during the cold flow test. The initial surge of LN2 into the system will cause the initial venting rate to exceed the normal venting rate.

The system shall remain in the LN2 environment until it is completely chilled. A completely chilled system is defined as one immersed in LN2 until excessive bubble formation ceases or until monitoring equipment indicates no further temperature decrease with extended duration of cold flow (15 minutes).

Post cold-shock testing procedures: Completion of the cold-shock test shall be documented after the following procedures have been accomplished:

a. System warmup: Remove the system from the cold environment and allow it to warm to ambient temperature. On some systems, it may be advantageous to use auxiliary heating devices, a water spray, or gas purge to reduce the warming time. If a water spray is used, it should be maintained until the system is above the freezing point of water, since the ice coating will act as an insulator and lengthen warmup time. CAUTION - Remove all traces of water

b. Retorquing: After the system has reached ambient temperature, all threaded fasteners and components should be retorqued. Refer to Appendix B.
c. Inspection Methods: Inspect the entire system for any evidence of failure. Particular attention should be given to welds and joints of dissimilar metals. Repair all defects.
d. Repaired systems: All defective portions of any system shall be subjected, after repair, to another cold-shock test before any other test is considered.

7.20.6 Low-Pressure Gas-Leak Testing

A low-pressure (5 to 10 psig) gas-leak test is optional for systems that are hydrostatically tested; however, all other systems shall be subjected to such a test. A suggested piping diagram for low-pressure gas leak testing is shown in Figure 1.

Guidelines: For cryogenic systems, the low-pressure leak test shall be performed after the cold-shock test (Section 7.20.5) and before the pressure strength test (Section 7.20.7 or 7.20.8). It is the initial test to be performed on all noncryogenic systems.

The purpose of the low-pressure gas-leak test is to indicate possible failure sites in a system before any form of high-pressure testing is undertaken. Although the system pressure is low, this test will indicate cracks and gross porosity in welds, leakage through threaded components, and improper sealing of gaskets, O-rings, and other joints.

Soap bubble test: The soap bubble test is recommended as a part of the low-pressure gas leak test, because it is easy to do, is quick, does not need exotic equipment, and is sensitive. The bubble test is performed by pressurizing the system to 5 psig or less with air and applying a film of bubble-testing liquid or a soap and water solution. Leaks are indicated by the bubbles formed by the leaking gas. Standard Glenn-prepared bubble-testing solutions or commercial "Leak Tec" fluid is recommended.

Simple equipment is required for a bubble test. Air or nitrogen gas shall be used for pressurizing the system. Helium gas is not recommended because the extra sensitivity is marginal and the cost of the gas is high.

The suggested procedure for a low-pressure gas-leak test is as follows:

a. Document performance of the test on the appropriate hydrotest or pneumatic test form.
b. Ensure that the system temperature is above the freezing point and below the boiling point of the bubble-testing liquid.
c. Clean the exterior of the system with an approved commercial solvent. Appropriate safety and environmental precautions shall be followed when solvents are being used. The surface must be clean before the bubble-testing

liquid is applied, because oil films or small amounts of soldering flux will destroy the liquid's bubble-producing capability.

d. Pressurize the system to 10% of the normal working pressure of the system, but do not exceed 5 psig. High pressures are not necessary for the leak test. Small leaks can be pinpointed without the hazards of high-pressure testing.
e. Apply bubble-testing liquid to all joints and seams of the system. Watch for the formation of bubbles. The gas bubbles will form at the leak, showing its precise location.
f. Repair all leaks before continuing the test sequence.

Figure 1: Typical Piping Schematic for Low Pressure Gas Leak Test, 5-10 psig. Figure 1 (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f1.pdf)

7.20.7 Hydrostatic Pressure Testing

This section provides basic information for hydrostatic testing of pressure systems and vessels. A typical schematic for a hydrostatic pressure test is shown in Figure 2 (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f2.pdf). These hydrostatic test guidelines apply to pressure systems and vessels designed for liquid, gas, steam, or cryogens. The guidelines are based on "ASME Boiler and Pressure Vessel Codes," the "ASME Piping Codes," and the "Glenn Safety Manual."

During a hydrostatic test, suitable precautions shall be taken to eliminate hazards to personnel in the event of rupture of leakage.

General guidelines: As assurance of safe hydrostatic pressure testing, the following recommendations are made:

a. The hydrostatic test pressure for piping systems and pressure vessels shall be determined in accordance with Section 7.20.4 of this chapter.
b. Hydrostatic test results shall be documented on appropriate forms (sample pressure vessel and piping system report forms are included in this chapter).

Test equipment: A safety relief device having a set pressure of the test pressure plus 50 psi or 110% of the test pressure, whichever is lower, shall be provided. The flow capacity of the relief device shall be at least equal to the output of the hydrostatic pressure source.

Water shall be used as a test medium. Test water shall be clean and of a quality that minimizes corrosion of the materials in the system under test. In the rare cases where water would contaminate or otherwise harm the system, consideration may be given to testing with another nontoxic fluid. Testing with a fluid other than water requires specific approval of the appropriate Safety Committee and the Glenn Safety Office.

A calibrated pressure gauge shall be used to indicate test pressure. It shall be visible to the operator of the pressure source and shall be calibrated against a standard deadweight tester or a calibrated master gauge. Gauges shall be recalibrated periodically or at any time there is reason to believe they are in error.

The range of the pressure gauge used to indicate test pressure should be about double the test pressure, but not less than 1.5 times the test pressure nor greater than 4 times the test pressure. Digital pressure gauges may be used if their accuracy is comparable to a calibrated dial pressure gauge.

For large vessels or systems where more than one pressure gauge is required, a recording gauge is recommended and may be substituted for one or more of the indicating gauges.

<u>Preliminary considerations:</u> Equipment that is not to be subjected to the pressure test shall be either disconnected from the system or isolated by a blank or similar device. Valves may be used for this purpose provided the valve closure is suitable for the proposed test pressure. Isolated equipment and piping not being tested shall be vented.

All welded, flanged, and threaded joints and connections not previously pressure tested shall be left uninsulated and exposed for examination during testing.

All stress loadings that may exist during this test shall be determined before the final hydrostatic test pressure is specified. The system shall never be subjected to stresses greater than the predetermined limit.

To locate major leaks in the system, a preliminary low-pressure gas-leak test not exceeding 5 psig may be performed before the hydrostatic pressure test (refer to Section 7.20.6). All leaks shall be repaired before proceeding with the hydrostatic pressure test.

Final hydrostatic test pressure is determined differently for pressure vessels and pressure systems (see Section 7.20.4).

Systems designed for gas or vapor may require temporary support or bracing to withstand the weight of the test fluid used in the hydrostatic pressure test. Adequate drainage or other provisions shall be available to remove the test fluid at the conclusion of the hydrostatic test.

Hydrostatic tests with water shall not be conducted when ambient temperature is below 40° F.

The temperature of the test fluid used for a hydrostatic test shall not be less than 60° F. However, if a particular situation warrants, a lower test temperature may be approved by the appropriate Safety Committee and Glenn Safety Office.

The temperature of water shall not be higher than 120° F, unless a higher test temperature is specified and approved. If a hydrostatic test is conducted with a water temperature higher than 120° F, the final, close visual examination at the test conclusion shall be conducted only after the water temperature falls below 120° F.

Vents shall be provided at all high points in the system to eliminate any air pockets formed while the system is being filled.

Before hydrostatic pressure is applied, the test equipment shall be examined to see that it is tight. All low-pressure filling lines and other components of the test equipment that should not be subjected to test pressure shall be disconnected or blanked off.

Procedure: The hydrostatic pressure shall be increased gradually until the system is subjected to 50% of the test pressure. At this point, the manual isolation valve shall be closed and the pressure held until the test gauge stabilizes. The system shall be closely examined for leaks and other deficiencies. Leaking will be indicated by a continuous decrease in the system pressure. Temperature changes in the system shall be monitored to correct pressure changes.

WARNING - If signs of yielding or failure of the system are observed, pressure shall be slowly decreased to zero.

After 50% of the test pressure is reached, the system pressure shall be increased in 10% increments (60%, 70%, 80%, 90%, and 100%) to final test pressure. At each pressure level, the manual isolation valve shall be closed and the pressure held until the test gauge stabilizes. The system shall be observed for an indication of leakage at each step. Observation shall be carried out from a safe distance. Continue increasing pressure until the full test pressure is applied.

After maximum test pressure is reached, the isolation valve of the hydrostatic pump shall be closed and the full test pressure continuously maintained for a minimum of 15 minutes. During this time, the system shall be observed for indications of leakage. Observation shall be carried out from a safe distance.

Following the application of full hydrostatic test pressure, the pressure shall be reduced to a value not less than the MAWP of the vessel or system. A close visual examination for leakage shall be made at all welds and all flanged and threaded joints.

Hydrostatic testing of a pressure vessel is a potentially hazardous procedure. All suitable safety precautions shall be taken to eliminate potential hazards to personnel and property.

Hydrostatic testing of pressure vessels: For pressure vessels designed in accordance with Division I of the "ASME Boiler and Pressure Vessel Code," Section VIII, the hydrostatic test pressure shall be at least 1.3 times the MAWP (see Section 7.20.4).

For pressure vessels designed in accordance with Division II of the ASME Boiler and Pressure Vessel Code, Section VIII, the hydrostatic test pressure shall be at least 1.25 times the design pressure (See Section 7.20.4).

Hydrostatic testing of piping systems: Expansion joints under test shall be provided with temporary restraints if the additional pressure load makes it necessary, or they shall be isolated with blanks or valving during the system test.

The hydrostatic test pressure at any point in the piping system shall not be less than 1.5 times the MAWP, but shall not exceed the maximum allowable test pressure of any nonisolated components, such as vessels, pumps, or valves (see Section 7.20.4).

All joints and connections shall be examined for leakage. The piping system, exclusive of possible localized instances at pump or valve packing, shall show no visual evidence of weeping or leaking.

Documentation: A checklist and a report (samples follow) are to be filled out for every hydrostatic pressure test of pressure vessels or piping systems.

Pressure Vessel Hydrostatic Test	
Checklist http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pvhc.pdf	Report http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pvhr.pdf
Piping System Hydrostatic Test	
Checklist http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pshc.pdf	Report http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pshr.pdf

7.20.8 Pneumatic Pressure Testing Guidelines

This section provides basic information for pneumatic testing of pressure systems and vessels. These pneumatic testing guidelines apply to pressure systems and vessels designed for liquid, gas, steam, or cryogenics. The guidelines are based on the "ASME Boiler and Pressure Vessel Codes," the "ASME Piping Codes," and the "Glenn Safety Manual."

These guidelines apply to Section 7.20.4, "Alternate Test 2, Operating Pressure Pneumatic Test," with the exception that test pressure for the operating pressure pneumatic test is equal to system operating pressure.

General guidelines: These general guidelines govern pneumatic pressure testing; however the decision to apply a pneumatic test instead of a hydrostatic test is restricted to the following situations:

a. The pressure system is designed or supported in a manner that unquestionably cannot be safely filled with liquid.
b. The configuration of the pressure system is such that it cannot be dried, and traces of the test medium cannot be tolerated.
c. A hydrostatic test would damage linings or internal insulation.

Note: Variance from these procedures requires Area Safety Committee and Glenn Safety Office concurrence.

Use of compressed gas as test medium is hazardous. Precautions shall be taken to ensure that adequate protection is provided to prevent injury to personnel and damage to property from missile fragments, shock waves, or other consequences of a rupture or leakage during a pneumatic test. Pneumatic testing shall always be conducted using the two-man buddy system (see Ch. 22 of the GSM) http://osat-ext.grc.nasa.gov/gso/manual/chapter_22.pdf

Pneumatic test pressure for piping systems and pressure vessels shall be determined in accordance with Section 7.20.4 of this chapter.

Pneumatic test results shall be documented on appropriate forms; sample pressure vessel and piping system report forms are included in this chapter.

A suggested piping diagram for the pneumatic pressure test is illustrated in Figure 3. (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f3.pdf)

Test equipment: A safety relief device having a set pressure of the test pressure plus 50 psi, or 110% of the test pressure, whichever is lower, shall be provided. The flow capacity of the relief device shall be at least equal to the output of the pneumatic pressure source.

The gas used as the test medium shall be nonflammable and nontoxic. Air or nitrogen gas are the preferred pressurizing fluids. In addition, it shall not be vented in a confined area. This eliminates the possibility of breathing undesirable or hazardous materials that may reside within the hardware.

A calibrated pressure gauge shall be used to indicate test pressure. It shall be visible to the operator of the pressure source and shall be calibrated against a standard deadweight tester or a calibrated master gauge. Gauges shall be recalibrated at any time that there is reason to believe that they are in error.

The pressure range of the test gauge shall not be less than 1.5 times the test pressure nor greater than 2 times the test pressure. Digital pressure gauges may be used if their accuracy is comparable to a calibrated dial pressure gauge.

For large vessels or systems where more than one pressure gauge is required, a recording gauge is recommended and may be substituted for one or more of the indicating gauges.

Before applying pneumatic pressure, the test equipment shall be examined to ensure that it is tight. All low-pressure filling lines and other components of the test equipment that should not be subjected to test pressure shall be disconnected or blanked off.

Preliminary considerations: The temperature of the test medium used to apply a pneumatic test is determined differently for pressure vessels and pressure systems (see Section 7.20.8).

All stress loadings that may exist during this test shall be determined before the final pneumatic test pressure is specified. The system shall never be subjected to stresses greater than the predetermined limit.

Equipment that is not to be subjected to the pressure test shall be either disconnected from the system or isolated by a blank or similar device. Valves may be used for this purpose, provided the valve closure is suitable for the proposed test pressure. Isolated equipment and piping not being tested shall be vented.

All welded, flanged, and threaded joints and connections not previously pressure tested shall be left uninsulated and exposed for examination during testing.

Procedure: To locate major leaks in the system, a preliminary low-pressure gas-leak test not exceeding 5 psig shall be performed before other methods of leak testing (refer to Section 7.20.6).

When the leak-test pressure of 5 psig has been reached, the system under test shall be isolated from the pneumatic pressure source with a hand valve. The test gauge shall be observed for at least 15 minutes to ensure the leak tightness of the system. Leaking will be indicated by a continuous decrease in the system pressure. Temperature changes in the system shall be monitored to correct for pressure change due to temperature change.

The pneumatic pressure shall be increased gradually until the system is subjected to 50% of the test pressure. At this point, the pressure shall be held until the test gauge is stable, and the system shall be closely examined for leaks and other deficiencies.

After 50% of the test pressure is reached, the system pressure shall be increased by 10% increments to the final test pressure (60%, 70%, 80%, 90%, and 100%). The manual isolation valve of the pneumatic pressure source shall be closed, and pressure shall be held until the test gauge is stable.

At each step, the system test pressure gauge shall be observed from a safe distance for indication of leaks.

WARNING - If signs of yielding of failure of the system are observed, pressure shall be slowly decreased to zero.

After full test pressure is reached, the isolation valve of the pneumatic pressure source shall be closed and the full test pressure shall be continuously maintained for a minimum of 15 minutes to ensure the quality of the system. During this time, the system test pressure gauge shall be observed from a safe distance for indications of leakage.

Following the application of the full pneumatic test pressure, the pressure shall be reduced to allow for close visual examination. The pressure should be reduced to different amounts for pressure vessels and pressure systems. All welds and all flanged and threaded joints shall be examined for evidence of leakage by using the leak-test procedure described in Section 7.20.6.

Local or close inspection of the system shall not be made while the test pressure is above the design operating pressure.

Pneumatic testing of pressure vessels: There are different guidelines for Division I and Division II pressure vessels.

Pneumatic testing of a pressure vessel is an extremely hazardous procedure. All suitable safety precautions shall be taken to eliminate potential hazards to personnel and property.

The following statements apply to pressure vessels designed in accordance with Division I of the "ASME Boiler and Pressure Vessel Code," Section VIII:

a. The pneumatic test pressure for all Division I vessels shall be at least 1.1 times the maximum allowable working pressure (see Section 7.20.4).
b. The temperature of the metal during the test shall be maintained to at least 30° F above the minimum design metal temperature to minimize the risk of brittle fracture.
c. Following the application of the full pneumatic test pressure as prescribed in these guidelines, the pressure shall be reduced to 80% of the test pressure, to allow for close inspection of the system.

The following statements apply to pressure vessels designed in accordance with Division II of the "ASME Boiler and Pressure Vessel Code," Section VIII:

a. The pneumatic test pressure for all Division II vessels shall be at least 1.15 times the design pressure (see Section 7.20.4).
b. The temperature of the metal during the test shall be at least 60° F to reduce the risk of brittle fracture.
c. The temperature of the vessel and the pressurizing medium shall be approximately equal before the test pressure is applied.
d. Following the application of the full pneumatic test pressure as prescribed in these guidelines, the pressure shall be reduced to the greater of the design pressure or 75% of the test pressure, to allow for close inspection of the system.

Pneumatic testing of piping systems: The following guidelines are specific to piping systems undergoing pneumatic test:

a. Expansion joints shall be provided with temporary restraints for the additional pressure load under test, or they shall be isolated during the system test.

b. All joints and connections shall be examined for leakage. The piping system, exclusive of possible localized instances at the pump or valve packing, shall show no visual evidence of leaking.
c. For piping designed in accordance with ASME B31.1, "Power Piping Code," the pneumatic test pressure at any point in the piping system shall not be less than 1.2 nor more than 1.5 times the design pressure of the piping and shall not exceed the maximum allowable test pressure of any nonisolated components such as vessels, pumps, or valves (see Section 7.20.4).
d. For piping designed in accordance with ASME B31.3, "Process Piping," the pneumatic test pressure at any point in the piping system shall be at least 1.1 times the system design pressure (see Section 7.20.4).
e. The metal temperature during the pneumatic test shall be a minimum of 10° Fahrenheit above the ductile-to-brittle transition temperature of the material.
f. Following application of the full pneumatic test pressure as prescribed in these guidelines, the pressure shall be reduced to the lesser of the design pressure or 100 psig, to allow for close inspection of the system.

Documentation: A checklist and a report are to be filled out (samples follow) for every pneumatic pressure test of pressure vessels or piping systems.

Pressure Vessel Pneumatic Test	
Checklist http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pvpc.pdf	Report http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pvpr.pdf
Piping System Pneumatic Test	
Checklist http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pspc.pdf	Report http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_pspr.pdf

7.20.9 Other Leak-Testing Methods

In general, all systems specified by the design engineer shall be leak tested. The leak test is the final test in any test sequence described in this section. It shall be performed on a high-pressure system only after the system has been hydrostatically or pneumatically tested (refer to Section7.20.7 or 7.20.8).

A leak test of greater sensitivity than the initial low-pressure gas-leak test (Section 7.20.6) shall be used as a final test of system integrity. This final test could be the high-pressure bubble test, the change-in-pressure test, or the mass spectrometer test.

Only one of these tests is required for acceptance; the design engineer may specify the test.

High-pressure bubble test: This test is identical to the low pressure gas leak test described in Section 7.20.6, except that the system is pressurized to the normal working pressure of the system. The following equipment, conditions, and procedures are necessary for the bubble test.

a. Pressurizing gas: Air or nitrogen gas shall be used for pressurizing the system. The extra sensitivity of helium gas may be warranted only for high-pressure helium and hydrogen systems.
b. Bubble-testing fluid: Standard NASA-prepared bubble-testing solutions are recommended. Commercial "Leak Tec" fluid is equivalent to the NASA solution.
c. Pressurizing piping schematic: The piping diagram for high-pressure bubble testing is illustrated in Figure 4. http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f4.pdf
d. Temperature of system: The system shall be at a temperature that is above the freezing point and below the boiling point of the bubble-testing liquid.
e. Cleanliness: The exterior of the system must be cleaned (when practical) with an approved commercial solvent. It is essential that the surface be clean prior to the application of the soap solution, because oil films or small amounts of soldering flux will destroy the bubble-producing quality of the soap solution.
f. Pressurization: The system shall be slowly pressurized to the normal working pressure of the system.
g. Location of leaks: The bubble-testing liquid should be applied to all joints and seams of the system. Watch for the formation of bubbles. The gas bubbles issuing from a leak will show its precise location. Depressurize the system and repair all leaks before continuing the test sequence.

Figure 4 - Typical piping schematic for operating pressure test. (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f4.pdf)

Change-in-pressure test: This test is performed by evacuating the interior of the system and monitoring the rate of pressure increase with the pump isolated from the system. Although it is difficult to pinpoint the exact source of a leak with this test, the overall leak rate of the system can be easily established. Before this test is attempted, be certain that the system has sufficient strength to withstand evacuation.

When the results of this test are analyzed carefully, exceedingly low leak rates can be measured. The sensitivity of this test is comparable to the high-pressure bubble test described previously.

Equipment: The equipment necessary for this test is as follows:

a. Vacuum gauge: A thermocouple or Pirani gauge having a range of approximately 1 to 1,000 microns is required for this test. The gauge sensing tube shall be connected with as short a tube as possible to the system being evacuated. Because this type of gauge is somewhat inaccurate and the test is based on a relative change, the vacuum gauge does not have to be calibrated. For additional information on the operation of the gauge, check the manufacturer's literature.

b. Vacuum pump: For most applications, a mechanical (rotary) vacuum pump is desired. The vacuum pump should have a "blank off pressure" of no more than 25 microns. The pump shall be connected to the system with as short a length of tubing as possible. To ensure a rapid pump-down time, the evacuation line shall be no smaller than the evacuation inlet of the pump. A flexible connection installed between the pump and the system will reduce vibrations.
c. Vacuum valve: A valve intended for vacuum usage is required to isolate the system under test. The valve should be located as close to the system as possible and have an opening at least equivalent to the inside diameter of the evacuation line.
d. Thermometer: A thermometer or thermocouple should be installed in the system to measure the temperature of the evacuated region.

Procedure: Evacuate the system to a pressure of at least 100 microns. This will allow the pressure rise to be monitored for at least a tenfold increase with the vacuum gauge described in paragraph (a). Inability to evacuate the system to a pressure of 100 microns can usually be traced to one or more of the following conditions:

- High magnitude of leaks
- System contaminants, particularly water
- Inadequate evacuation system

Isolate the vacuum pump from the system by closing the vacuum valve.

Monitor the time, system pressure, and temperature over a suitable time period to establish the leak rate.

Leak-rate formula: The leak rate calculation is illustrated in Figure 5. (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f5.pdf)

Outgassing: The initial evacuation of any system is likely to result in gas evolution, which is often called "outgassing." The outgassing component of pressure rise may be easily separated from the leakage component by plotting the system pressure as a function of time. Two distinct degrees of curvature are evident in a typical system pressure plot. Between points A and B, the system pressure rises at a continually decreasing rate; hence, a curve of decreasing slope is evident. Between points B and C, the straight line indicates a uniform rate of pressure increase. (See Figure 5 http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f5.pdf)

The significance of each curve may be explained by considering the nature of both outgassing and leakage. The rate of outgassing is exponentially dependent on pressure. As the system pressure increases, the rate of outgassing decreases; however, the rate of leakage is constant over the pressure range since the same differential pressure of about 760,000 microns is maintained. Therefore, the initial curve from point A to point B represents both outgassing and leakage, with outgassing being the principle cause of the rate of system pressure rise near point A.

At point B, the system pressure has increased to above the vapor pressure of the outgassing source; therefore, the straight line between points B and C represents system leakage. Only the straight line section of the curve should be used for determining leak rates. The curve between points A and B should be ignored.

Mass spectrometers: A mass spectrometer leak detector is an electrically tuned instrument for detecting the presence of a tracer gas. It is the most sensitive commercially available leak detector. These detectors use a helium tracer gas to detect leaks as low as 10^{-9} cm^3/sec

Principle of operation: Ions of the tracer gas are produced in a source chamber by electron bombardment from a hot tungsten filament. The ions are accelerated electrostatically through an analyzer magnet field. The helium ions are deflected by a permanent magnetic field and collected on a target plate connected to the grid of an electrometer tube. The output of the electrometer tube is amplified and presented on a multirange output meter.

Liquid nitrogen traps, roughing and oil range diffusion pumps, and various valves are incorporated on the mass spectrometer to maintain proper operating conditions in the analyzer tube.

Standard leak: A standard leak is essential if quantitative measurements are to be made, since sensitivity can vary widely as the spectrometer tube becomes contaminated. Large decreases in sensitivity can be encountered when the leak detector is connected to large, separately pumped systems (only a portion of the trace gas entering the leak arrives at the spectrometer tube).

Helium probe: The helium probe consists of a 10^{-4} cm^3/sec leak detector in a probe tube at the end of several feet of flexible tubing. It is used for testing devices that are filled with helium under pressure. Because of the rapid diffusion of helium coming out of a leak, it is unlikely that a leak smaller than 10^{-6} cm^3/sec can be found by this method.

Pressure testing and procedure: This method of testing is useful in testing large tanks or objects that cannot withstand internal vacuum. The system is pressurized with helium tracer gas, and the exterior of the system is sniffed with the helium probe. When the probe is passed over a leak, the outflowing helium gas is detected. To proceed with the test do the following:

a. Pressurize the system with helium gas to 10% of the normal working pressure, but do not exceed 20 psig. High pressure is not desired for this test since it only increases diffusion in air. If the system is large, a tracer gas consisting of a combination of helium and nitrogen gas may be used for testing. The percentage of nitrogen gas to helium gas may be as large as 95% by volume.
b. Carefully sniff the exterior of the system with the helium probe. Any helium entering the probe will be recorded as a leak. This test may be made more sensitive by surrounding the helium probe with a small enclosure. The enclosure

will prevent wind from rapidly dispersing the helium and allow helium to build up in the enclosure until the concentration is sufficient to be detected by the mass spectrometer.

Vacuum testing and procedure: Vacuum testing is the most sensitive form of leak detection. Here, the system under test is evacuated either with the vacuum system in the leak detector, or if the system is of appreciable size, with an auxiliary pumping system. A helium jet is sprayed over the suspected areas of the system to locate the leaks. Proceed with the vacuum test as follows:

a. Evacuate the system with either the pumping system incorporated in the mass spectrometer or an auxiliary pumping system. Generally, the lower the system pressure, the more sensitive the test. The most sensitive test occurs when the high vacuum leak detector pumping system can solely maintain the vacuum in the system at or below 10^{-4} mm Hg.
b. Spray the exterior of the system with the helium tracer gas. The tracer gas will be drawn into the system through the leaks and recorded on the mass spectrometer. The exact location of leaks may be determined by using a very fine helium jet or by "bagging" the suspected area to ensure the accumulation of a helium pocket.
c. Repair each leak immediately on detection, either temporarily, or preferably, permanently. As each leak is repaired, the system pressure will be lowered and smaller leaks may be located.

The mass spectrometer is a highly complicated instrument. The outline for leak testing with a mass spectrometer presented herein is for general information only. Anyone attempting to use a mass spectrometer should be thoroughly familiar with its theory and operation. There is no substitute for properly applied experience in leak detection with a mass spectrometer.

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APPENDIX A – RESTRICTED DISTANCE FOR PNEUMATIC PRESSURE TESTING

Safety of personnel, buildings, and equipment must be of primary concern during a pneumatic pressure test. A sudden rupture will generate a pressure wave that can cause damage. Some consequences of blast overpressure are listed here:

OVERPRESSURE (psi)	EFFECT
0.5	Shatters glass windows
1	Knocks personnel down
1 to 2	Causes failure of standard house construction
2 to 3	Shatters concrete or block walls 8 inches thick
5 to 15	Ruptures eardrum
30 to 40	Damages lungs
130 to 180	Kills 50% of people

Assuming a 0.5 psi overpressure, we can determine the restricted distance for pneumatic tests.

During the application of pneumatic pressure, all nonessential personnel shall be located a safe distance from the test. Buildings and major structures inside this restricted area shall be protected. This graph was derived from a curve showing pounds of open-field TNT-equivalent explosive per 1000 ft^3 of gas as a function of rupture pressure. The figure was originally published in "Liquid Hydrogen Storage and Transmission," by the Los Alamos Scientific Laboratory, Liquid Hydrogen Safety Committee. Although the curve was plotted for hydrogen gas, the difference in adiabatic expansion between air and hydrogen is slight. The curve has been accepted by the safety committee. The TNT-equivalent per 1000 ft^3 of gas has been converted into restricted distance by information originally supplied by the Bureau of Mines, Boulder, Colorado.

The restricted distance from Figure 6 (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f6.pdf) need not be strictly adhered to if alternate precautions are taken for personnel. Some alternate safety precautions include locating personnel behind adequate blast shields, sandbags, or other unmovable objects. Sample calculations for determining the restricted distance, adjusted for the effect of volume, during a pneumatic test are as follows;

EXAMPLE 1

METHOD FOR CALCULATING RESTRICTED DISTANCE FOR A PRESSURE VESSEL

Given the following:

Pressure Vessel Volume $\left(V_{Vessel}\right)$ = $300 \bullet ft^3$

MAWP = $2000 \bullet \frac{lb}{in^2}$

Pneumatic Test Pressure (P_{test}) = $2000 \bullet \frac{lb}{in^2} \bullet 1.25 = 2500 \bullet \frac{lb}{in^2}$

From Figure 6, the restricted distance for a 1000 ft^3 system with,

$$P_{test} = 2500 \bullet \frac{lb}{in^2} \text{ is, } \quad D_{1000} = 550 \bullet ft$$

The formula to obtain the restricted distance for the tank volume is:

$$D_{Vessel} = \frac{D_{1000} \bullet \sqrt[3]{V_{Vessel}}}{10 \bullet ft}$$

Therefore, the restricted distance for the pressure test is:

$$D_{Vessel} = \frac{550 \bullet ft \bullet \sqrt[3]{300 \bullet ft^3}}{10 \bullet ft}$$

$$D_{Vessel} = 370\, ft$$

EXAMPLE 2

METHOD FOR CALCULATING RESTRICTED DISTANCE FOR A RESEARCH RIG

1. Determine the total system volume:

Given the Maximum Allowable Working Pressure for the system:

$$MAWP = 240 \frac{lb}{in^2}$$

Given a 100 cc sample cylinder:

$V_{cylinder} = 100cm^3$ or $V_{cylinder} = 3.531 \bullet 10^{-3} \bullet ft^3$

Given system tubing that is 0.25 in O.D. with an 0.035 inch wall. The cross-sectional area of the tube is:

$$A_{tube} = \frac{\pi \bullet [0.25 \bullet in - (2 \bullet 0.035 \bullet in)]^2}{4}$$

$A_{tube} = 0.0254 \bullet inches^2$ or

$A_{tube} = 1.767 \bullet 10^{-4} \bullet ft^2$

Given a conservative estimate that there is 20 feet of tubing in the system. The volume of the tubing is:

$V_{tube} = 20 \bullet ft \bullet A_{tube}$ $V_{tube} = 3.534 \bullet 10^{-3} \bullet ft^3$

Therefore, the total system volume is:

$V_{total} = V_{cylinder} + V_{tube}$ $V_{total} = 7.065 \bullet 10^{-3} \bullet ft^3$

2. Determine the restricted distance, given the test pressure and total system volume.

The test pressure to be applied to the system:

$P_{test} = 1.25 \bullet MAWP$ $P_{test} = 300 \bullet \frac{lb}{in^2}$

From Figure 6, the restricted distance for a 1000 ft^3 system with

$P_{test} = 300 \bullet \frac{lb}{in^2}$ is, $D_{1000} = 225 \bullet ft$

The correction formula to obtain the restricted distance for the actual system volume is:

$$D_{system} = \frac{D_{1000} \bullet \sqrt[3]{V_{total}}}{10 \bullet ft} \qquad D_{system} = \frac{225 \bullet ft \bullet \sqrt[3]{7.065 \times 10^{-3} \bullet ft^3}}{10 \bullet ft}$$

Therefore, the restricted distance for the pressure test is:

$D_{system} = 4.3 ft$

Figure 6 - Restricted distance for pneumatic pressure testing. (http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_f6.pdf)

APPENDIX B – FASTENER TORQUE TABLE

Suggested Maximum Torque Values for Fasteners of Different Materials

TORQUE, in.-lb.							
Bolt size	**Low carbon steel**	**18-8 Stainless**	**Brass**	**Silicon bronze**	**Aluminum 24-ST-4**	**316 Stainless**	**Monel**
2-56	2.2	2.5	2.0	2.3	1.4	2.6	2.5
2-64	2.7	3.0	2.5	2.8	1.7	3.2	3.1
3-48	3.5	3.9	3.2	3.6	2.1	4.0	4.0
3-56	4.0	4.4	3.6	4.1	2.4	4.6	4.5
4-40	4.7	5.2	4.3	4.8	2.9	5.5	5.3
4-48	5.9	6.6	5.4	6.1	3.6	6.9	6.7
5-40	6.9	7.7	6.3	7.1	4.2	7.1	7.8
5-44	8.5	9.4	7.7	8.7	5.1	9.8	9.6
6-32	8.7	9.6	7.9	8.9	5.3	10.1	9.8
6-40	10.9	12.1	9.9	11.2	6.6	12.7	12.3
8-32	17.8	19.8	16.2	18.4	10.8	20.7	20.2
8.36	19.8	22.0	18.0	20.4	12.0	23.0	22.4
10-24	20.8	22.8	18.6	21.2	13.8	23.8	25.9
10-32	29.7	31.7	25.9	29.3	19.2	33.1	34.9
1/4"-20	65.0	75.2	61.5	68.8	45.6	78.8	85.3
1/4"-28	90.0	94.0	77.0	87.0	57.0	99.0	106.0
5/16"-18	129	132	107	123	80	138	149
5/16"-24	139	142	116	131	86	147	160
3/8"-16	212	236	192	219	143	247	266
3/8"-24	232	259	212	240	157	271	294
7/16"-14	338	376	317	349	228	393	427
7/16"20	361	400	327	371	242	418	451
1/2"-13	465	517	422	480	313	542	584
1/2"-20	487	541	443	502	328	565	613
9/16"-12	613	682	558	632	413	713	77
9/16"-18	668	752	615	697	456	787	855
5/8"-11	1000	1110	907	1030	715	1160	1330
5/8"-18	1140	1244	1016	1154	798	1301	1482
3/4"-10	1259	1530	1249	1416	980	1582	1832
3/4"-16	1230	1490	1220	1382	958	1558	1790
7/8"-9	1919	2328	1905	2140	1495	2430	2775
7/8"-14	1911	2314	1895	2131	1490	2420	2755
1"-8	2832	3440	2815	3185	2205	3595	4130
1"-14	2562	3110	2545	2885	1995	3250	3730

TORQUE, ft.-lb.							
Bolt size	**Low carbon steel**	**18-8 Stainless**	**Brass**	**Silicon bronze**	**Aluminum 24-ST-4**	**316 Stainless**	**Monel**
1 1/8"-7	310	413	337	383	265	432	499
1 1/8"-12	322	390	318	361	251	408	470
1 1/4"-7	432	523	428	485	336	546	627
1 1/4"-12	396	480	394	447	308	504	575
1 1/2"-6	732	888	727	822	570	930	1064
1 1/2"-12	579	703	575	651	450	732	840

This table of torque values is reprinted by courtesy of the H. M. Harper Company. The table is intended as a guide only. Tests were conducted on dry or near dry products. Mating parts were wiped clean of chips and foreign matter.

APPENDIX C – PRESSURE RATINGS

The information in the following tables will furnish personnel with a quick reference list of pressure ratings for piping, tubing, and flanges. These tables should be reviewed thoroughly before making a piping selection. Temperature and type of pipe (i.e., welded or seamless, threaded or unthreaded) have an effect on pressure ratings. Any question related to these tables should be directed to the appropriate engineering office.

Formula for computing MAWP: The maximum allowable working pressures for 304 stainless steel pipe (A-312 Grade TP304) and tubing (A-269 Grade TP304) given in Tables I to III were calculated by a rearrangement of the formula given in paragraph 304.1.2 of ASME B31.3, "Process Piping ".

The rearranged formula is:

$$P = \frac{2 * S * E * (t - C)}{D - 2Y * (t - C)}$$

Where

- P maximum non-shock internal service pressure, psig
- S maximum allowable stress in pipe wall due to maximum internal service pressure at the service temperature, psi
- E dimensionless basic weld joint quality factor from B31.3 (equals 1.0 for seamless pipe or tubing; 0.85 for welded pipe or tubing)
- t design thickness of the pipe wall, inches (12.5% less than the nominal wall thickness of any given stainless steel pipe size)
- D outside diameter of pipe, inches
- C allowance for threading, mechanical strength, or corrosion, inches
- Y dimensionless coefficient for austenitic steels (equals 0.4 for temperatures up to and including 1150° F)

For Type 304 seamless pipe, the stress value used in these calculations was 20,000 psi, with E = 1.0, as specified in ASME B31.3. This value is equal to 2/3 of yield strength and is applicable for services where mechanical and hydraulic shocks are not excessive. For high levels of severity of service, a lower allowable stress value should be used (consult with the design engineer). To find allowable working pressures for welded pipe, multiply the tabulated value by E = 0.85. Schedule 5 pipe is available only in welded construction; therefore, the "S x E" value used in this report is 17,000 psi (i.e., 20,000 x 0.85). Schedule 10 pipe is available in both welded and seamless construction; the Figures shown are for welded Schedule 10 pipe. To convert these values to seamless Schedule 10 pipe, multiply by 1.17 (i.e., 1 / 0.85).

The value of C used in these calculations was zero for unthreaded pipe. For threaded pipe, C = 0.05 inch for pipe sizes 3/8 inch and smaller, and it is equal to the thread depth for pipe sizes 1/2 inch and larger, as specified in ANSI B1.20.1, "Pipe Threads, General Purpose (Inch)”. To convert the tabulated value for 304 stainless steel to the allowable working pressure for a different alloy, multiply by the appropriate factor.

Table I. - Factors for Determining Maximum Allowable Working Pressure

		Type		Grade
Alloy	Correction factor (a)	Pipe	Tubing	Tubing
Stainless Steel 304	1.00	A-312	A-269	TP304
Stainless Steel 304L	.83	A-312	A-269	TP304L
Stainless Steel 316	1.00	A-312	A-269	TP316
Stainless Steel 316L	.83	A-312	A-269	T316L
Inconel (<5 in. diameter)	1.00	B-167	B-167	600 or UNS NO 6600
Monel (<5-in. diameter)	.93	B-165	B-165	400 or UNS NO 4400

Note: (a) For temperatures from -325° to +100° F.

Correction factor is based on allowable stress values from ASME B31.3. For more detailed pressure ratings, or for different materials, either refer to the current edition of ASME B31.3 or contact the appropriate engineering office.

TABLES

(The tables listed below may also be viewed as hard copies at GRC Library - Glenn Safety Manual)

Table II. - Technical Data for A-312, Grade TP304 Seamless Piping http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table2.pdf
Table III. - Technical Data for A-269, Grade TP304, Seamless Tubing http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table3.pdf
Table IV. - Maximum Flange Pressure Ratings http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table4.pdf
Table V. - Sizes and Areas of Copper Tubing http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table5.pdf
Table VI. - Maximum Allowable Internal Working Pressures for Seamless Copper Tubing http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table6-7.pdf
Table VII. - Allowable Stresses for B-75 Seamless Copper Tubing http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table6-7.pdf
Table VIII. - Rated Internal Working Pressures of Joints Made From Copper Tubing and Soldered Fittings http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table8.pdf
Table IX. - Internal MAWP for Parker Stainless Steel "Triple-Lok" Flared Fittings http://osat-ext.grc.nasa.gov/gso/manual/chapter_07_table9.pdf

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